Boron-Aluminum Relationships in the Soil and in Plant Uptake

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A DISSERTATION PRESENTED TO THE GRADUATE COUNCIL OF
THE UNIVERSITY OF FLORIDA
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE
DEGREE OF DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA
August, 1959

ACKNOWLEDGMENTS

The writer wishes to express his deepest appreciation to Dr. F. B. Smith, Head of the Soils Department, whose interest and assistance made this work possible.

The writer also wishes to extend his most sincere gratitude to Dr. J. G. A. Fiskell who supervised the research reported herein and to Dr. G. D. Thornton who planned the necessary course of studies.

Appreciation is expressed to Dr. L. C. Hammond, Dr. T. W. Stearns, and Dr. W. D. Ash whose teaching and services as Supervisory Committee members have meant so much to the writer.

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INTRODUCTION

The soils of a good many farming areas in the United States have been found to be deficient in boron that is available for plant use. The symptoms displayed by plants suffering from a lack of sufficient boron are quite striking and have been described for the major fruit, vegetable, and legume crops which are sensitive to a deficiency of boron in plant nutrition. The status of boron and its major roles in plant nutrition and physiology have probably been studied more thoroughly in the United States than any of the other micronutrients.

An intimate relationship has been shown to exist between boron and calcium, both in the soil and within the plant. In the presence of an excess of calcium in comparison to boron in the soil, a large part of the available boron is rendered unavailable for plant use. On the other hand, a deficient supply of boron in growth media has been shown to greatly reduce the absorption of calcium by the plant roots.

During the period between 1920 and 1930, aluminum received a large amount of interest from soil scientists mainly because of its toxic effects on plants. However, this interest died and until recent years very little experimental work was done on the aluminum problem. An aroused awareness has been displayed during the past few years with respect to the importance of aluminum in the soil. This has been due principally to the prevalence of aluminum in the soil and its great influence on soil properties, such as pH and the ionic charge on the exchange complex.

It has been known for several years that aluminum precipitated phosphorus within the roots of plants, but relationships between aluminum and other elements in the soil and within the plant have not been studied to any great degree. The relationships between aluminum and boron, chemically and physically, presuppose that there may be a relationship which will manifest itself in the physiological reactions within the plant.

This study was undertaken to test the hypothesis that aluminum may influence the uptake of boron from the growth media by the plant. The relationships between boron and calcium and between aluminum and calcium were also objects of the study.

REVIEW OF LITERATURE

Boron in Plant Nutrition

The earliest recorded use of boron as a plant nutrient was in France by Peligot (50) in an attempt to find a plant preservative. He tested borax, boric acid, and potassium borate as soil amendments at the rate of 2 grams of each material in 5-liter pots. The test plants were killed in a few days after emerging, presumably as a result of the toxicity produced by the large amount of boron.

Agulhon (2), also in France, was probably the first to realize that boron was a useful element in the growth of higher plants. Small amounts of boron added to culture solution and to soil resulted in marked increases in the dry weights of plants, especially in the Gramineae family. In 1910 Agulhon (3) grew wheat, oats, peas, radishes, and other plants in sterile media, in sterile soil, and in the open field using varying levels of boron fertilization. He determined that each species had an optimum boron requirement and there was a reduction in chlorophyll content and in root development if this level was increased.

Although Agulhon had previously shown boron to be a useful element in plant nutrition, it remained for Warington (63) in 1923 to prove conclusively that it was an essential element in the growth of the broad bean, *Vicia faba*. In 1927, Brenchley and Warington (10) produced evidence that boron is indispensable to the species *Glycine hispida*, *Phaseolus multiflorus*, *Trifolium incarnatum*, and *T. pratense* for the completion of the growth cycle. These tests were conducted in culture solution which failed

to support plant growth when boron was withheld, but sustained growth when boron was supplied in any of the 32 chemical forms tested. The effectiveness of the boron was not influenced by the form in which it was supplied or the pH value of the nutritive solution.

Boron Deficiency Symptoms in Plants

A deficiency of boron in the nutrition of a plant produces specific visual characteristics in the plant itself. Brenchley (9) found that in the absence of boron plants die from the apices, anatomical changes occur, and the tissue darkens and disintegrates. He also found that root-nodule bacteria (Bacillus radicicola) failed to develop normal nodules on broad bean roots in the absence of an adequate supply of boron.

Boron deficiency symptoms may vary considerably among different species of plants, but they will generally appear somewhat along the lines of deficiency symptoms in sunflowers (13). In the sunflower there is first a yellowing at the base of the leaves of the growing tip. These leaves gradually turn yellow throughout, then become white and finally die. The older leaves nearest the tip turn yellow at the base, become thickened and draw in and under in the form of a half-circle. These older leaves have a glossy green sheen on the tips and are yellow to brown at the base. The old leaves droop, the internodes shorten, and rosetting occurs. The leaves of the flattened tip may become thick and brittle, necrosis of the tip is rapid, and the entire center may become reddish-brown.

Boron deficiency symptoms in clover (65) are manifested by a red discoloration of the leaves which starts on the tips of the younger leaves. The red coloration soon extends throughout the leaf surface and the leaves later turn brown and die. In alfalfa boron deficiency appears as a yellow-

ing of the terminal leaves and death of the growing tips. This disease of alfalfa is commonly known as "alfalfa yellows."

The Uptake of boron by Plants

Plant species vary considerably in their need for boron and their ability to absorb boron from the soil. Lestrand and De Waal (7), in France, compared the boron content of 30 species of plants grown in the same soil type without added boron. The plants were analyzed for boron by colorimetric and volumetric methods. Boron contents were found to range from a low of 2.3 parts per million (ppm.) in barley, rye, and wheat to a high of 94.7 ppm. in poppy.

One of the most complete and revealing works in the area of boron-plant relationships was that of Eaton (19). In outdoor pot experiments, he grew 72 crops using 58 varieties of 30 plant species in sand culture fertilized with rates of a trace, 1, 5, 10, 15, and 25 ppm. boron. The objectives were to determine plant boron deficiency and toxicity symptoms, to determine growth reactions, and to determine boron accumulation characteristics. The plants in these tests segregated themselves into one of three groups: boron sensitive, boron semitolerant, or boron tolerant. Observations were made of each species for visible boron deficiency and toxicity symptoms. It is interesting to note that some plants showed signs of deficiency at the trace level and signs of toxicity at the 5 ppm. level. Chemical analyses were made of the boron content of the stems, leaves, and tubers. Eaton found that there is a wide range in the uptake of boron among species and within species grown in different rates of boron fertilization.

The Role of Boron in Plant Physiology

The specific role that boron plays in the physiology of higher plants has not been definitely determined. There have been approximately fifteen distinct roles suggested for boron. The necessity for an adequate supply of boron in the setting of seeds by legumes is well documented. Davis (17) obtained an increase from 90 pounds of crimson clover seed from plots receiving no added boron to 800 pounds from plots fertilized with borax. This test was conducted on a Norfolk loamy sand where lime, in addition to boron, gave further increases in yield. West (65) obtained an increase of approximately 300 pounds of crimson clover seed per acre by use of 10 to 30 pounds of borax per acre on Hartsell fine sandy loam. Grizzard and Matthews (24) obtained a marked increase in the production of alfalfa seed from the application of 15 pounds of borax per acre on a Cecil sandy loam. Others (47, 48, 51, 52) have shown that boron is of decided benefit in the development of seeds. Boron also affects pollen germination (1).

The accumulation of carbohydrates in the leaves of boron-deficient plants had been observed by numerous investigators. Haas and Klotz (26, 27) showed this phenomenon to occur in the case of citrus. White-Stevens (66) observed that leaves of turnips growing in a boron deficient medium were out of proportion in weight as compared to the roots. The leaves were filled with an excess of carbohydrates in all forms, whereas, the roots were markedly deficient in carbohydrates. Wadleigh and Shive (62) observed an accumulation of carbohydrates in cotton leaves grown in a boron deficient medium.

The accumulation of carbohydrates in the leaves naturally indicates that the translocation of carbohydrates from the site of synthesis, i.e.,

the fruit, roots, or tubers, has been interrupted. Several workers have shown that there is an increase in the per cent of sugars in the fruits or roots of plants upon the addition of boron. Cook (16) obtained an increase in the sugar content of sugar beet roots from the addition of boron to a Thomas sandy loam. Harris (28) showed an increase in the sugar content of turnip and carrot roots from the application of boron to a well-limed peat soil, a Milner clay, and an Alderwood sandy loam in British Columbia. Jacob and White-Stevens (33) reported an increase in the sugar content of cantaloupes induced by an application of boron to the soil, a Dukes sand with pH 5.8 to 6.0.

Gauch and Dugger (21) used the Warburg apparatus to measure the uptake of oxygen by lima bean and pea root tips in the absence and in the presence of boron. In the presence of 5 ppm. boron there was an increase of 50 per cent in respiration by the root tips. By immersing an excised tomato leaf in a solution of labeled sucrose these workers obtained an increase of 35 per cent in radioactivity within the leaf when the sugar solution contained 10 ppm. boron.

It has also been postulated that boron has a function in nitrogen metabolism, active salt absorption, hormone production and movement, water relations, and other minor plant processes. Beckenbach (5) found that tomato plants grown in nutrient solution culture in the presence of an ample nitrate supply required much more boron than nitrate-starved plants. Shive (57) detected a high accumulation of ammonium nitrogen in plants grown in sand culture in the absence of boron. It, therefore, appears that boron is functional in normal protein metabolism through its effect on carbohydrate utilization.

Beckenbach (5) postulated that the phosphate and borate ions may act interchangeably as plant juice buffers, or in precipitating out excess cations by forming insoluble salts. Tomato plants were found to require more boron when grown in phosphate deficient solution.

Boron appears to be functional in the absorption of water by plants and its translocation within the plant. Chandler (11) found the percentage of moisture in boron deficient rutabaga plants to be lower than in plants receiving adequate boron in the solution culture. Leaf (36) found that tobacco plants growing in solution with no boron absorb less moisture than plants growing in the presence of boron.

Calcium-boron Relationship in Plant Nutrition

There can be no doubt that there exists an intimate relationship between calcium and boron in the nutrition of plants, as was suggested first by Brenchley and Warington (14). These workers showed that broad beans growing in solution culture were unable to obtain sufficient calcium for growth in the absence of boron. In a subsequent experiment Warington (64) found the amount of calcium absorbed by broad beans decreased when boron was not supplied in the nutrient solution.

Jones and Scarseth (34) made a study of several Indiana farm crops in greenhouse pot experiments using varying amounts of boron in limed and unlimed soils. The results of these experiments showed that plants grow normally only when an optimum calcium/boron ratio exists (this ratio varies over a wide range among plant species, i.e., from 100/1 for sugar beets to 1200/1 for tobacco according to the authors). Boron toxicity to plants may occur on strongly acid soils, containing small amounts of calcium, from the uptake of very little boron. On the other hand, boron deficiency may occur

as alkaline soils, as overlimed soils, due to the low availability of boron.

Minarik and Shive (46) found there was an optimum boron level in the solution culture at which a maximum amount of calcium is taken up by soybean plants. However, when the boron concentration was low enough in the solution to retard plant growth, the accumulation of calcium was also at its lowest point. The optimum boron concentration in the nutrient solution was stated to range between 0.025 ppm. and 1.00 ppm.

Henderson and Veal (30) showed that boron in the solution culture gave an increase in growth and an increase in calcium absorption by blue lupine plants. The concentrations of boron used in their solutions were 3.75, 5.00, and 7.50 ppm. which would probably result in severe toxic effects in other plant species.

Reeve and Shive (53) grew tomatoes in sand culture with six levels of calcium (5, 10, 50, 100, 250, and 500 ppm.) and six levels of boron (0.001, 0.01, 0.5, 5, and 10 ppm.). Toxic effects from boron were produced by the higher rates (5 and 10 ppm.), but these effects were nullified by the higher rates of calcium (250 and 500 ppm.). This inhibition effect by calcium on boron absorption was also manifested by a marked decrease in boron accumulation within the plant tissue. Boron deficiency effects from low levels of boron in solution were greatly enhanced by increasing the calcium concentrations.

Aluminum in Plant Nutrition

The status of aluminum in the nutrition of plants has been concerned mainly with the problem of toxicity effects in soils of high acidity. In 1918 Hartwell and Pember (29) conducted an extensive search in an attempt to ascertain the causative substance which prevented a response in

the growth of rye from the addition of lime to a highly acid soil, but at the same time there was an increase of two to threefold in the yield of barley. These two crops were grown in solution and sand cultures under increasingly acid conditions and they were affected alike by the acid. When aluminum sulfate was substituted for the sulfuric acid, barley yields were depressed to almost one-half of the rye yields. Therefore, the conclusion was that aluminum in the acid soil was the primary reason for the differential effect from lime.

In 1923 Blair and Prince (8) grew barley in leachates collected from limed and unlimed plots which had been fertilized with ammonium sulfate for a period of 15 years. During this period the plant yields from the unlimed plots had shown a steady decline. The barley in leachates from the limed plots showed good growth as compared to the poor growth of the barley in the leachates from the unlimed plots. Chemical analyses revealed a content of almost 32 ppm. of aluminum in the leachates from the unlimed soil and no aluminum in those from the limed soil. Blair and Prince also grew barley in nutrient solution with added aluminum sulfate and found it to be quite toxic. The aluminum sulfate lowered the pH values of the culture, but solutions brought to the same pH with sulfuric acid grew healthier plants.

McLean and Gilbert (43) found aluminum in solution culture to be quite variable in its toxic effects among plant species. Lettuce, beets, timothy, and barley were found to be sensitive to 2 ppm. of aluminum in solution; radishes, sorghum, cabbage, oats, and rye were sensitive to 7 ppm. of aluminum; and corn, turnips, and redtop were sensitive to 14 ppm. of aluminum. The effect of plant growth as changes in the pH of the solu-

tions did not increase or decrease the sensitivity of the plants to aluminum. This was pointed out by the fact that the original pH value of the solutions was changed from 4.5 to 6.4 by barley, to 3.8 by lettuce, to 6.3 by beets, and to 6.3 by timothy.

Gilbert and Pember (22) grew lettuce in solution culture with and without aluminum and in varying hydrogen ion concentrations. The lettuce grew equally well in solutions of pH 3.2 to pH 7.3 in the absence of aluminum, but when aluminum sulfate was added to the solutions toxicity symptoms were rapidly developed. These authors (23) also presented evidence that weeds and grasses vary widely in their tolerance to aluminum in solution culture. They found plants such as dandelions, Kentucky bluegrass, and chickweed to be sensitive to aluminum in concentrations of 3 to 6 ppm., but crabgrass and redtop were tolerant of 32-80 ppm. of aluminum.

The Effects of Aluminum Toxicity in Plants

The effects of aluminum toxicity are manifested mainly by the root systems of affected plants. McLean and Gilbert (43) found that toxicity symptoms start as a discoloration of the secondary roots which then become stunted and eventually the entire root system appears to be deranged. McLean and Gilbert (44) found the aluminum accumulates in the protoplasm and particularly in the nuclei of the cortex. The injury, therefore, is localized principally in the roots causing dwarfing and inhibition of branching. The poisoning also results in a decreased ability on the part of the affected plant to absorb dyes, water, and nutrient salts.

It is interesting to note that the above authors showed aluminum did not have to be in solution in order for plants to absorb it, and that plants could readily absorb colloidal aluminum. They grew barley with the

roots in contact with precipitated aluminum and produced equal toxicity effects as compared to the toxicity effects produced in roots growing in contact with aluminum in solution.

This intimate relationship between aluminum and the root systems of sensitive plants raises the question as to the actual entry of aluminum into the roots. Wright and Donahue (68) presented evidence that aluminum is not precipitated on the surface of the roots, but is absorbed into the root system. They used haematoxylin, which gives a red stain only in tissues containing aluminum, to stain barley roots grown in the presence and in the absence of aluminum. The internal cortical region as far as the endodermis was deeply stained in the roots that had been grown in the presence of aluminum. The outer wall of the endodermis also gave a deep stain, but the inner wall was practically free of the stain. Therefore, very little aluminum enters into the vascular system internal to the endodermis. Liebig et al. (37) observed that the leaves of lemon plants grown in the presence of aluminum in the solution culture contained only 22 ppm. of aluminum as compared to 1000 ppm. in the roots.

Wright and Donahue (68) also showed, by the use of radioactive phosphorus, an internal precipitation of phosphorus by aluminum. In this aspect of aluminum toxicity, Wright (67) found a greater percentage of phosphorus in barley plants grown in the presence of aluminum than in its absence. The phosphorus percentage was especially high in the roots thus indicating the mutual precipitation of aluminum and phosphorus in the roots.

Aluminum as a Plant Stimulant

In contrast to the recognized toxic effects of aluminum on plants, several workers have shown that aluminum may be of benefit to plant growth.

Sommer (48), in an attempt to show that aluminum is essential to the growth of plants, used purified aluminum in solution culture. She obtained a small increase in the growth of peas and a marked increase in the growth of millet. Haas (25) obtained favorable growth responses in Valencia orange trees through the addition of aluminum to solution and soil cultures.

Lipman (38), studying the hypothesis that aluminum may be essential for the growth of higher plants, used sunflowers and corn as indicator plants. This experiment was in solution culture containing 1 ppm. of aluminum with no attempt being made to control the pH of the solution. The experiment was undecisive as to the essential role of aluminum, but there was an increase in the weight of the sunflower heads and a twofold increase in corn ear weight due to aluminum effects.

Liebig *et al*. (37), in attempting to decrease copper toxicity to citrus, studied the effects of aluminum on copper in solution culture. The addition of aluminum at rates as low as 0.1 ppm. to the solution decreased copper toxicity. This effect on copper was not due to the prevention of copper absorption through the roots, but to some detoxifying influence of aluminum on copper in the roots. There, also, was shown to be a stimulating effect from aluminum on root growth when the aluminum was applied at rates of 2.5 to 5.0 ppm. to the solution. Evidence was presented that aluminum may depress the absorption of other micronutrients if they are in short supply. For example, the uptake of boron was depressed in the stems and all portions of the roots when aluminum was present in the solution. The cause of this effect from aluminum was not known.

Aluminum-Accumulating Plants

Some plant species are heavy accumulators of aluminum. Chenery (13) found very high quantities of aluminum in tea leaves and the aluminum content increased with the age of the leaves. Young tea leaves were found to contain only 100 ppm. of aluminum, but this amount increased to 5,000-16,000 ppm. of aluminum as the leaves matured. In contrast the secondary roots contained 800 ppm. of aluminum and the primary roots 500 ppm. of aluminum.

The strongest accumulator of aluminum is probably the family Symplocaceae, or sweetleaf tree, which contains as high as 13.7 per cent aluminum oxide (24). A Symplocos tinctoria tree near Gainesville, Florida, was found to contain 7.67 per cent aluminum oxide. Hickory leaves contain from 0.30 to 3.86 per cent aluminum oxide and the closely related pecan contains about 0.64 per cent aluminum oxide in the leaves.

Aluminum-Calcium Relationship

A possible antagonism between aluminum and the uptake of calcium by plants has been suggested by Schmehl et al. (55). During an absorption time of 35 hours in nutrient solutions containing 16 ppm. of aluminum and 100 ppm. of aluminum, the absorption of calcium-45 by alfalfa was greatly reduced over that of the control. The uptake of calcium from the solution containing 16 ppm. of aluminum was only one-tenth that of the control.

Aluminum as a Soil Constituent

Aluminum occurs in the soil as a constituent of undecomposed rock fragments, in secondary aluminosilicate clays, as solid or hydrosol hydrated oxides, as phosphates, and in the ionic form (32). Gibbsite, alu-

minum hydroxide, may constitute as high as 30 per cent of the inorganic soil colloid.

McLean et al. (42) have presented evidence that aluminum is the major cation present on the cation exchange complex of clay minerals. They electrodialyzed 8 Ohio soils and 3 clay minerals for several weeks and then saturated them with calcium or potassium. The soils and clays were allowed to equilibrate for 3 to 5 months and aluminum was then extracted. A Wooster silt loam with a cation exchange capacity of 5.0 milliequivalents per 100 grams of soil had 94 per cent of aluminum on the unsaturated complex and 48 per cent aluminum on the 100 per cent base saturated complex. A Brookston silty clay loam with a cation exchange capacity of 29.6 milliequivalents per 100 grams contained 60 per cent aluminum when base unsaturated and 23 per cent aluminum when 100 per cent base saturated. The clay mineral Illite with a cation exchange capacity of 32.5 milliequivalents per 100 grams contained 31 per cent aluminum when base unsaturated and 28 per cent aluminum when base saturated. Bentonite, which has a cation exchange capacity of 112 milliequivalents per 100 grams, contained 81 per cent aluminum on the base unsaturated exchange complex and 28 per cent aluminum on the base saturated complex.

It is reasonable to assume that soil acidity is due to the presence of hydrogen ions in the soil solution. Therefore, in titrating a soil or clay mineral with a base, the reaction would presumably be due to the replacement of hydrogen ions on the exchange complex with the cations of the base. However, Low (39) observed that in the potentiometric titration curve of an electrodialyzed Bentonite clay mineral a definite break occurred long before the end point was reached. He postulated that this break occurred

when the hydrogen ions were completely replaced on the exchange complex and the replacement of aluminum began. In order to prove this hypothesis Low prepared hydrogen-aluminum bentonite clays and titrated them with sodium hydroxide. The break in the titration curves occurred when the hydrogen was replaced and replacement of aluminum had begun, thus showing the hypothesis is be true.

Boron and Aluminum Chemical Relationships

Boron and aluminum are the primary members in Group III of the periodic table (35). Boron, the only nonmetal in Group III, occurs as complex silicates and aluminates. The main boron-bearing mineral in tourmaline which has the general formula $H_2MgNa_9Al_3(BO)_2Si_4O_{20}$. Boron, also, combines with aluminum to form the alloys AlB_2 and AlB_{12} which are of a degree of hardness greater than carborundum. Aluminum reacts with boron sulfide to form the metallic sulfide and possibly the boride.

The hydroxide of aluminum is amphoteric, and the following values may be given for the basic and acidic dissociation constants:

$$Al(OH)_3 = Al^{+++} + 3\ OH^- \quad K_a = 1.9 \times 10^{-33}$$

$$Al(OH)_3 = H^+ + H_2AlO_3^- \quad K_a = 4 \times 10^{-13}$$

$$H_2AlO_3^- + H^+ = H^+ + H_2O + AlO_2^- \quad K_a = 1 \times 10^{-10}.$$

The dissociation constant for boric acid is of the same order of magnitude as the dissociation constant for aluminic acid. The reaction occurs as follows:

$$H_3BO_3 = H^+ + H_2BO_3^- \quad K_a = 5.8 \times 10^{-10}.$$

The structures of gibbsite, $Al(OH)_3$, and boric acid, H_3BO_3, are isomorphous (45). In the amorphous state colloidal alumina hydrogel may become crystalline hydrate on prolonged contact with water and is then with diffi-

ently soluble in hydrochloric, nitric, or acetic acid. Alumina hydrogels have the property of absorbing acids, bases, and salts from solution (as in the absorption of sulfate in the preparation of the hydrogel from alum). Boric acid does not coagulate colloidal alumina as does hydrochloric, nitric, sulfuric, and many organic acids.

In view of the close chemical relationships between boron and aluminum, it is logical to assume that there should be competition or a mutual antagonism when the two elements are in close contact with one another. This line of reasoning has not been explored and is one of the bases for the study reported herein.

EXPERIMENTAL PROCEDURE

Outdoor Lysimeter Experiment

First Lysimeter Test

This test was designed to study the effect of aluminum applied to the soil on the uptake of boron by sunflowers. The sunflower was chosen as the indicator plant in this experiment because it has been shown to be the best indicator plant of boron deficiency (13, 14, 15, 20, 40, 48, 49, 56, 58, 61). The lysimeters were 3- and 5-gallon glazed crocks provided with bottom drainage through polyethylene tubing opening into 1-gallon glass jars. The crocks were placed in the soil and alined in 2 rows of 32 crocks oriented north and south. The row to the east was composed of the 5-gallon crocks and the row to the west was composed of 3-gallon crocks. The soil contained in the lysimeters was a Blanton fine sand which had been used in other boron studies several years prior to this test. The soil had lain fallow during the ensuing time between the end of the earlier experiment and the start of the present experiment.

The experimental design was a 4 x 4 factorial of four levels of boron and four levels of aluminum, comprising a total of sixteen treatments. Each treatment was replicated four times with two replications in each row of lysimeters. Boron was applied as boric acid (H_3BO_3) at rates of 0, 0.5, 1.0, and 2.0 pounds of boron per acre. Aluminum was applied as aluminum sulfate, $Al(SO_4)_3 \cdot 18H_2O$, at rates of 0, 10, 20, and 40 pounds of aluminum

per acre. The following fertilizer rates per acre were applied as reagent grade salts: 286 pounds of ammonium nitrate, 192 pounds of potassium dihydrogen phosphate, 34 pounds of potassium chloride, 50 pounds of magnesium sulfate, 1000 pounds of calcium carbonate, 2.8 pounds of manganese sulfate, 2.5 pounds of copper sulfate, 2.5 pounds of zinc sulfate, 6.1 pounds of ferrous ammonium sulfate, and 0.34 pounds of sodium molybdate. The fertilizer was mixed thoroughly with the top three inches of soil ten days prior to planting.

On July 14, 1958, five sunflower seeds were planted in each lysimeter. When the sunflower seedlings had reached a height of approximately four inches, they were thinned to two plants per pot. At approximately three weeks of age, the smaller sunflower plant in each lysimeter was removed and nitrogen was applied at the rate of 100 pounds per acre. The remaining sunflower plants were allowed to grow for ten weeks before harvesting.

Throughout the period of this experiment leachates were collected and analyzed for boron and aluminum.

Second Lysimeter Test

The 3- and 5-gallon lysimeters used in the first lysimeter test were again used in this test. The Blanton fine sand was removed and replaced with Blichton fine sand obtained from the farm of Mr. Loonis Blitch, Alachua County Agent, south of Williston, Marion County, Florida. The Blanton soil series is formed from very thick beds of marine sands. The Blichton series differs in that it is formed from weathered low grade phosphatic deposits with a covering of marine sands and sandy clays.

In this test only 27 crocks of each size were used. The 3-gallon crocks were filled with 18 pounds of subsoil (6 to 12 inches) in the bottom

half and 18 pounds of topsoil (0 to 6 inches) in the top half. The 3-gallon crocks were filled with 10.3 pounds of subsoil and 10.5 pounds of topsoil.

Rutabaga test

The 3-gallon crocks were fertilized with reagent grade salts at the equivalent rates of 600 pounds of 10-10-10 fertilizer per acre plus 100 pounds of calcium, 50 pounds of magnesium, 1 pound of manganese, 1 pound of copper, 1 pound of zinc, 1 pound of iron, and 0.5 pound of molybdenum. The experimental design was a completely randomized 3 x 3 factorial of three levels of boron and three levels of aluminum replicated three times. The boron was applied as boric acid at rates of 0, 1, and 2 pounds of boron per acre and the aluminum as aluminum sulfate at rates of 0, 20, and 40 pounds of aluminum per acre. All fertilizer materials were thoroughly mixed in the top three inches of soil and Purple Top rutabagas were planted on September 8, 1958. At approximately one month of age the rutabagas were thinned to 3 plants per crock and sidedressed with ammonium nitrate at the equivalent rate of 100 pounds of nitrogen per acre. The rutabaga tops and roots were harvested on January 7, 1959.

Lettuce test

The 3-gallon crocks were fertilized again at the same rates of materials as were applied to the rutabagas except that aluminum was not applied. The Iceberg variety of lettuce was planted on February 17, 1959. At approximately one month of age the lettuce was thinned to 15 plants per crock and sidedressed with ammonium nitrate at the rate of 100 pounds of nitrogen per acre. The lettuce plants were harvested on May 4, 1959.

Clover test

The 3-gallon crocks were fertilized with the same materials and the same rates as the 5-gallon crocks except nitrogen was omitted and calcium carbonate was applied at the rate of 1000 pounds per acre. Louisiana S-1 white clover was planted on September 27, 1958, and harvested on March 23, 1959.

The crops grown in the second lysimeter test were watered during periods of dryness with deionized water at the rate of one and one-half quarts per 5-gallon crock and one quart per 3-gallon crock. The total amount of leachates from each lysimeter was recorded and samples were analyzed for boron and aluminum contents.

Solution Culture Experiment

First solution culture test

This test was designed to measure the possible effects of aluminum on the uptake of boron by sunflowers. Amber-colored jars having a capacity of 2 liters were used to contain the solution in which the sunflowers were grown. Hoagland's solution 1 (31) containing potassium dihydrogen phosphate, potassium nitrate, calcium nitrate, magnesium sulfate, manganese chloride, zinc sulfate, copper sulfate, and molybdic acid in deionized water was used as the basic solution. Ferrous sulfate was substituted for the iron tartrate in Hoagland's solution and no boron was added. The experimental design was a 3 x 3 factorial with three levels of boron and three levels of aluminum. Boron was supplied as boric acid at rates of 0, 0.3, and 1.0 ppm. of boron and aluminum was supplied as aluminum sulfate at rates of 0, 0.5, and 1.0 ppm. of aluminum. Each treatment was replicated four times in a randomized complete block design. Aeration was supplied for

four hours each day from a constant pressure source of compressed air fed through individual glass capillary tubes into each jar. The air pressure at each jar was regulated by means of screw clamps on the rubber tubing.

Sunflower seeds, purchased locally of unknown variety, were germinated and allowed to grow to a height of approximately three inches in white quartz sand. The sand was previously washed several times in approximately 25 per cent sulfuric acid followed by several rinses in deionized water. The sunflower seeds were planted in the sand, which had been maintained with the basic nutrient solution, on October 25, 1958. On November 2, the sunflower seedlings were placed in the jars containing the solution culture treatments. Plant support in the jars was provided by wrapping nonabsorbent raw cotton around the stem just above the root system and placing the plant through a hole in the cork top of the jar.

The solution cultures were renewed each week with fresh solution of the same composition. At each change the pH of the old solutions and the pH of the new solutions were determined by the use of a Beckman model-180 pocket pH meter. Water losses through plant transpiration were replaced daily with deionized water. The sunflower plants were harvested on November 29.

<u>Second solution culture test</u>

This test was designed the same as the first solution culture test with the exception that the aluminum levels were increased to 0, 1, and 2 ppm. Sunflower seeds were planted in the sand on December 19, 1958, and the seedlings were placed in the jars on December 26. The same procedure, with respect to changing the solutions, was followed as in the first test. The sunflower plants were harvested on February 7, 1959.

Third solution culture test

This test was designed to measure the effect of increasing concentrations of aluminum in solution on the uptake of boron from a constant level of 1 ppm. of boron in the solution. The nine treatments, replicated four times, were composed of the basic nutrient solution plus 0, 2, 4, 6, 8, 10, 12, 14, and 16 ppm. of aluminum. Sunflower seeds were planted in the sand on February 4, 1958, and transplanted to the jars on February 20. The solutions were changed once each week, as in the previous tests. The sunflower plants were harvested on April 4.

Boron-Aluminum Survey of Several Soil Series

A survey was conducted of five representative soil series in the central and southern sections of Florida. Soil samples from tomato fields were collected in conjunction with leaf samples from the tomato plants growing in the soils. Soil samples and leaf samples of palmetto plants were also collected from uncultivated fields of the same soil type adjacent to the cultivated fields. The objective of this survey was to determine if there was a correlation between the aluminum and boron contents of the cultivated or uncultivated soils and of plant species growing in the soils. This survey was conducted during December, 1958.[1] Table 1 shows the locations and soil types of the areas that were sampled.

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[1]Mr. W. T. Jacobs, Jr., Assistant Soil Surveyor, Soils Department, University of Florida, provided valuable assistance in locating the areas to be sampled and in identifying the soil types from which the samples were to be taken.

TABLE 1.-Locations and soil types from which plant and soil samples were collected

Sample No.	Location	Owner	Soil Type
1	Fort Myers Lee County	William Nychyk	Immokalee fine sand
2	Zolfo Springs Hardee County	Dick Davis	Leon fine sand
3	Zolfo Springs Hardee County	Carlton Farms	Blanton fine sand
4	Rubonia Manatee County	Harllee Farms	Leon fine sand (heavy substratum)
5	Big Bend Hillsborough County	Elsberry Farms	Ruskin fine sand

Laboratory Studies

A simple laboratory experiment was designed to test if aluminum hydroxide would remove boron from solution. The test was conducted with three replications of 0.5 gram portions of aluminum hydroxide in 100 milliliters of solution containing 0, 1, 10, 50 and 100 ppm. of boron. The solutions were shaken for one-half hour and centrifuged. Boron determinations were made of the supernatant liquid. In every case there was 100 per cent recovery of boron, therefore showing that aluminum hydroxide does not remove boron from solution.

Plant and Soil Analyses

All plant material grown and collected in these experiments was dried at 70° C., weighed, and ground in a Wiley micromill to pass a 20-mesh screen. The plant material was analyzed for boron, calcium, and aluminum contents. In cases where there was sufficient vegetative material 2.5 grams were ashed in porcelain crucibles at 600° C. for one hour. In all

other cases the total amount of plant material obtained was ashed. The ash was taken up in 30 milliliters of 0.36 N sulfuric acid and all undissolved material was removed by centrifuging. Plant root material was prepared for analysis in the same manner, except that only 0.5 gram portions were ashed. This is the method of boron extraction from plant material as outlined by Berger and Truog (6).

The analysis of plant material for boron was by the modified quinalizarin method of MacDougall and Biggs (41). In the modified method ordinary 95-96 per cent sulfuric acid is used in the place of the 98 per cent sulfuric acid specified in the original Berger and Truog method (6). The amount of quinalizarin was increased from 25 ~~grams~~ mgms per liter of acid specified in the original method to 45 ~~grams~~ mgms per liter in the modified method. In the development of color 1 milliliter of plant extract was mixed with 10 milliliters of quinalizarin and sulfuric acid solution in boron-free 15 milliliters test tubes and allowed to stand for 24 hours. A Beckman model B colorimeter set at 620 millimicrons was used to measure the per cent of light transmission by the color lake, using a blank prepared from 1 milliliter of 0.36 N sulfuric acid and 10 milliliters of quinalizarin solution set at 100 per cent transmission. Boron values were calculated from a standard curve prepared from the colorimeter readings of known amounts of boron (from 0.5 microgram to 0.6 micrograms of boron).

Boron was extracted from soil samples by refluxing 20 grams of air-dried soil, which had been passed through a 20-mesh screen, in 40 milliliters of hot water for 5 minutes. The samples were allowed to cool and the suspended soil was thrown down in the centrifuge. A 20-milliliter aliquot was withdrawn from each sample and placed in a 50-milliliter porcelain crucible. Two milliliters of saturated calcium hydroxide were added and the

samples were evaporated to dryness over a hot-water bath. The samples were then ignited in a muffle furnace for one hour at 600° C. to destroy nitrates (concentrations of nitrates greater than 25 ppm. react with quinalizarin to give a deeper blue color than boron). The residue was taken up in 5 milliliters of 0.36 N sulfuric acid and centrifuged. One milliliter portions were withdrawn and mixed with 10 milliliters of quinalizarin and sulfuric acid solution for color determination.

In analyzing the leachates from the lysimeters for boron, nitrates were found to be present in amounts great enough to interfere with color development. In order to overcome this interference 20-milliliter aliquots were withdrawn from the leachates and processed in the same manner as the soil extracts.

The determination of aluminum was by the modified aluminon method of Yuan and Fiskell (69). Suitable aliquots of the plant extract, described in the boron determinations, were pipetted into 50-milliliter beakers. Two milliliters of a 5 per cent hydroxylamine hydrochloride solution were added to reduce the iron. Thirty milliliters of distilled water were added, followed by 20 milliliters of aluminon reagent buffered at pH 4.6. The solution was adjusted to pH 3.8 using normal hydrochloric acid or ammonium hydroxide and boiled for 4 or 5 minutes. After cooling the solutions were brought to 50 milliliters volume with distilled water and allowed to stand for an hour or longer. The per cent transmittancy was read at 540 millimicrons on the Beckman model B using a reagent blank set at 100 per cent transmittancy. A standard curve was prepared from known amounts of aluminum (from 5 micrograms to 70 micrograms of aluminum).

Aluminum and calcium were extracted from soil samples by shaking

10 grams of the sieved soil in 2 N ammonium acetate buffered at pH 4.8 for one hour. The extractant was filtered through number 30 Whatman filter paper. The soil was washed four times with 50-milliliter portions of extracting solution and the combined filtrates were made to a volume of 250 milliliters. Suitable aliquots of the filtrates were pipetted into 50-milliliter beakers and aluminum determinations were made in the same manner as for plant samples.

For calcium determinations of plant material 2 milliliters of the extractant for boron analyses were diluted to 25 milliliters volume in 0.36 N sulfuric acid. A Beckman model DU flame emission spectrophotometer set on 554 millimicrons maximum transmission was used for calcium analyses. A standard curve was prepared with known amounts of calcium in 0.36 N sulfuric acid using a 920 ppm. of calcium standard set at 100 per cent transmission. Calcium determinations of soils were made in the ammonium acetate extractants which required the preparation of a standard curve from known amounts of calcium in ammonium acetate.

RESULTS AND DISCUSSION

Outdoor Lysimeter Experiment

First Lysimeter Test

The soil used in this test was sampled prior to treatment and analyzed for hot-water soluble boron. The pH of each sample was determined by the glass electrode using equal parts of soil and water. The results of the boron analyses and of the pH determinations are presented in Table 2[1], and Tables 1 and 2 of the Appendix. The average boron content of the soil contained in the 64 lysimeters was 0.68 ppm. and the average pH was 6.11. Statistically, there was no significant difference among the lysimeters in either boron content or pH, but there was a highly significant difference in pH between the two blocks of lysimeters, as the larger lysimeters contained soil with slightly higher pH than the smaller sized lysimeters. Six samples of soil in the lysimeters, selected at random, were analyzed for aluminum and calcium contents. The average aluminum content was 95 ppm. and the average calcium content was 12 ppm. This indicated a high aluminum saturation of the soil prior to fertilization. However, the availability of the aluminum was probably low since the soil pH was about 6.1, whereas the extraction of aluminum for analysis was made at pH 4.8, which was favorable for aluminum release from the exchange complex.

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[1]The values presented as tables in the "Results and Discussion" are averages of the replications of each treatment. The complete data, accompanied by analysis of variance tables, are presented in the tables of the Appendix.

TABLE 2.-The original hot-water soluble boron content and pH of soils to be used in the first lysimeter test

Pounds/acre of soluble aluminum to be applied	Pounds/acre of soluble boron to be applied								Average	
	0		0.5		1.0		2.0			
	B	pH	B	pH	B	pH	B	pH	B	pH
	ppm.		ppm.		ppm.		ppm.		ppm.	
0	.07	5.95	.07	6.08	.08	6.15	.08	6.21	.08	6.08
10	.07	6.13	.08	5.99	.07	5.93	.08	6.10	.08	6.04
20	.08	6.08	.08	6.20	.09	6.10	.07	6.12	.09	6.13
40	.08	6.13	.08	6.17	.07	6.27	.07	5.97	.07	6.13
Average	.07	6.09	.08	6.08	.09	6.13	.08	6.10	.08	6.11

The sunflowers were observed throughout their growth for signs of abnormalities that could be attributed to treatment effects. The plants did not exhibit any recognizable symptoms of boron deficiency or aluminum toxicity. The lack of boron deficiency signs in the sunflower plants growing in the lysimeters containing no added boron indicated that the boron in the soil available for plant absorption was adequate for plant growth. In view of the relatively high level of native soil aluminum, it appeared that because there were no manifestations of aluminum toxicity in the sunflower plants growing in the presence of the higher rates of added aluminum, the added aluminum was made unavailable by fixation at the high soil pH or by the phosphate addition. An alternative to the above postulation is that the sunflower plants were not sensitive to the toxic effects of aluminum.

The yield data for the sunflower plants grown in the first lysimeter test are presented in Table 3 and Appendix Table 3. Statistically, there was no significant difference in weights among the treatments, but there was a highly significant difference between the two blocks of lysimeters. This difference in weights was due to the heavier plants produced

in the larger lysimeters, which was to be expected because the roots of these plants had a greater soil area to use than the plants in the smaller lysimeters. Although treatment effects produced no difference in yield, there appeared to be a trend for the weights of the plants to decrease with increasing rates of aluminum and to increase with increasing rates of boron. The greatest average yield was 17.8 grams from the lysimeters which had received boron at the rate of 2 pounds per acre. The lowest average yield was 14.2 grams from the lysimeters which had received aluminum at the rate of 40 pounds per acre.

TABLE 3.-Effect of aluminum and boron applied to Blanton fine sand on the weights[1] of sunflower plants in the first lysimeter test

Pounds/acre of Al applied	Pounds/acre of B applied				Average
	0	0.5	1.0	2.0	
	g.	g.	g.	g.	
0	16.2	20.5	15.2	18.2	17.5
10	15.2	18.2	17.2	17.9	18.4
20	15.7	15.7	15.2	19.5	16.1
40	15.2	12.2	14.7	16.5	14.2
Average	14.6	16.4	15.4	17.8	16.1

[1]Oven-dry weights

The sunflower plants were measured from the surface of the soil to the tip of the plant in order to determine the effect of aluminum and boron on height. Unlike the yield data, boron had a highly significant effect on the height of the sunflower plants as shown in Table 4 and Appendix Table 4, and, in agreement with the yields, there was a highly significant difference in height between the two blocks of lysimeters. This difference was again due to the greater heights of the plants grown in the larger lysimeters. In contrast to boron, aluminum treatments had no effect on height nor was there an interaction effect from aluminum and boron appli-

sections. The highest average height was from the lysimeters which had received 0.5 pound of boron per acre and the lowest was from the check plots which had not received boron.

TABLE 4.-Effect of aluminum and boron applied to Blanton fine sand on the heights of sunflower plants in the first lysimeter test

Pounds/acre of Al applied	Pounds/acre of B applied				Average
	0	0.5	1.0	2.0	
	In.	In.	In.	In.	In.
0	33.4	38.0	32.0	35.0	34.6
10	30.0	39.4	33.0	34.1	34.0
20	31.0	37.7	36.4	38.4	36.0
40	29.2	32.5	34.0	33.5	32.2
Average*	31.2	37.2	34.0	35.5	34.4

*Least significant difference[2] between boron means at the .05 level is 5.4 inches and at the .01 level is 4.5 inches.

The boron contents of the sunflower plants are presented in Table 5 and in Appendix Table 5. There was a highly significant difference in boron uptake by the plants, which may be defined as the amount of boron found in the plants and is analogous to the boron content of the plants. The uptake of boron increased as the rates of boron applied to the soil increased. The check plots were significantly different, by the application of the least significant difference test, from the plots which had received boron and the plots receiving boron at the rate of 0.5 pound per acre were different from

[2] The least significant difference between boron means or aluminum means is shown where the analysis of variance (59) given in the corresponding Appendix table shows significance for these comparisons. In the above instance, only boron levels significantly affected the heights of the sunflower plants. Because the number of means is either four or three in this and subsequent tables, the least significant difference test is used. This difference is indicated at both the .05 and .01 level of probability when applicable. For example, where 0.5 pounds of B was added, the height was significantly greater at the .01 level than the control plants without added B, but not different than where the higher rates of B were used. Where a large number of treatment means, as in the interaction of B x Al, are significantly different, the standard error of the mean is shown so that interpretation by a multiple range test as proposed by Duncan (18) can be applied.

those receiving 1 and 0 pounds of boron per acre. The size differential between the lysimeters had an influence on the uptake of boron by the sunflower plants. There was no significant effect from aluminum applied to the soil on the uptake of boron.

TABLE 5.-Effect of aluminum and boron applied to Blanton fine sand on the uptake of boron by sunflower plants in the first lysimeter test

Pounds/acre of Al applied	Pounds/acre of B applied				Average
	0	0.5	1.0	2.0	
	ppm.	ppm.	ppm.	ppm.	ppm.
0	67	85	98	110	93
10	66	88	102	114	91
20	63	85	106	96	88
40	90	93	106	112	100
Average*	72	86	103	111	93

*Least significant difference between boron means at the .05 level is 13 ppm. and at the .01 level is 17 ppm.

The sunflower plants were not heavy accumulators of aluminum within the vegetative organs as was be seen in Table 8 and Appendix Table 6. The amount of aluminum taken up by the plants did not increase until the rate of applied aluminum reached 40 pounds per acre. Although there was no statistically significant aluminum and boron interaction or a significant effect from boron treatments, it is interesting to note that the highest absorption of aluminum was by the sunflower plants growing in the lysimeters which had received 40 pounds per acre of aluminum and boron at rates of 0 and 0.5 pound per acre. The uptake of aluminum by sunflower plants growing in these plots was 124 ppm. and 137 ppm., respectively. This suggested that there was a depressing effect from the boron treatments on the absorption of aluminum at the highest rate of aluminum applied.

There was a highly significant difference in the uptake of aluminum between sunflower plants grown in the larger lysimeters and those grown in the smaller lysimeters. The uptake of aluminum was much greater in the plants grown in the larger lysimeters. It may be recalled that the larger lysimeters had higher pH values than the smaller lysimeters and, therefore, the availability of the native aluminum should have been lower in the larger lysimeters. However, each lysimeter received an equal amount of calcium carbonate applied at the rate of 1000 pounds per acre, which probably brought the entire 64 lysimeters very close to the same pH. Therefore, it could be conjectured that as the sunflower plants increased in size, the uptake of aluminum also increased, resulting in a greater uptake of aluminum by the larger plants in the larger lysimeters as compared to those in the smaller lysimeters.

TABLE 8.-Effect of aluminum and boron applied to Blanton fine sand on the uptake of aluminum by sunflower plants in the first lysimeter test

Pounds/acre of Al applied	Pounds/acre of B applied				Average*
	0	0.5	1.0	2.0	
	ppm.	ppm.	ppm.	ppm.	ppm.
0	82	70	81	83	74
10	86	58	101	78	81
20	58	70	64	95	73
40	124	130	90	86	108
Average	83	83	85	86	86

*Least significant difference between aluminum means at the 0.5 level is 23 ppm. and at the .01 level is 29 ppm.

The calcium contents of the sunflower plants in this test were unaffected by the application of aluminum or by the application of boron to the soil. There was, however, a highly significant difference in calcium content between the two blocks of lysimeters. In this instance, the plants

growing in the smaller lysimeters had the greatest amount of calcium. The explanation for this is not clear; however, it may be possible that the greater amount of aluminum in the plants in the larger lysimeters resulted in a lower absorption of calcium by these plants. The calcium contents of sunflower plants are presented in Table 7 and Appendix Table 7.

TABLE 7.-Effect of aluminum and boron applied to Blanton fine sand on the uptake of calcium by sunflower plants in the first lysimeter test

Pounds/acre of Al applied	Pounds/acre of B applied				Average
	0	0.5	1.0	2.0	
	%	%	%	%	%
0	.43	.44	.45	.45	.44
10	.42	.47	.42	.47	.45
20	.43	.50	.38	.39	.43
40	.41	.43	.45	.41	.43
Average	.42	.46	.43	.43	.43

In order to determine the amounts of boron and aluminum removed by the drainage water from the individual lysimeters, leachates were collected periodically and analyzed for boron and aluminum. Ten milliliters were withdrawn from each leachate and analyzed for aluminum, but in no instance was the amount of aluminum in the samples great enough to be detected by the method of analysis used. The method of analysis was sensitive enough to detect 5 micrograms of aluminum with accuracy, but much smaller amounts of aluminum produced color sufficient to give a lower per cent of light transmission by the colorimeter. In no instance was the color found in the leachates deeper than the color produced by the blank. It could be assumed, therefore, that aluminum in the soil was not mobile to any great extent and was not removed by percolating water.

In contrast to aluminum, a large percentage of the applied boron was removed by the drainage water as shown in Table 8 and Appendix Table 8. It was quite apparent that boron was very mobile in the soil and was readily removed by percolating water. The difference in the amount of boron leached from the individual lysimeters was highly significant at the different rates of boron applied to the soil, but there was no such effect from aluminum or from an aluminum and boron interaction. There was, also, a highly significant difference between the two blocks of lysimeters which was to be expected because of the greater amounts of boron applied to the larger lysimeters and the greater amounts of water which percolated through them.

TABLE 8.-Effect of aluminum and boron applied to Blanton fine sand on the total amounts of boron in lysimeter leachates in the first lysimeted test

Pounds/acre of Al applied	Pounds/acre of B applied				Average
	0	0.5	1.0	2.0	
	mg.	mg.	mg.	mg.	mg.
0	0.37	1.61	2.43	3.25	1.91
10	0.25	0.75	2.40	3.00	1.07
20	0.40	1.44	2.02	1.73	1.37
40	0.43	1.20	1.80	2.06	1.64
Average*	0.45	1.08	2.33	2.70	1.70

*Least significant difference between boron means at the .05 level is 0.46 milligrams and at the .01 level is 0.62 milligrams.

It could be concluded from the results of this experiment that the addition of aluminum to the soil had little effect on the ability of sunflower plants to obtain boron from the soil. It could be concluded, also, that boron applied to the soil had little effect on the uptake of aluminum by sunflower plants. However, there appeared to be a decided decrease in the uptake of aluminum by sunflower plants growing in the lysimeters which

had received aluminum at the rate of 40 pounds per acre and boron at the rates of 1 and 2 pounds per acre. The uptake of calcium by the sunflower plants was not influenced by the addition of either aluminum or boron to this soil.

Second Lysimeter Test

The Blichton fine sand used in this experiment was analyzed for boron, aluminum, and calcium. The averages of three separate analyses of the 0 to 6 inch-depth of soil were 0.03 ppm. of boron, 80 ppm. of aluminum, and 10 ppm. of calcium. The averages of three separate analyses of the 6 to 12 inch depth were 0.04 ppm. of boron, 125 ppm. of aluminum, and 10 ppm. of calcium. The average pH of both depths was 5.40. This soil was selected because of its extremely low content of hot-water soluble boron.

<u>Rutabaga test</u>

The rutabaga plants grown in this test exhibited early symptoms of boron deficiency in all lysimeters which had received no added boron. Boron deficiency symptoms in turnips were manifested as a thickening of the younger leaves, followed by a crinkled, twisted appearance (11). The older leaves were smaller than normal and presented a variegated color of yellow and purplish-red blotches. The roots of affected plants were much smaller than normal and had a distorted shape. The root surface was generally rough and wrinkled. The interior of the root contained dark brown, water-soaked areas commonly recognized as symptoms of the brown heart disease.

The brown heart disease may be seen quite clearly in Plate I. The roots marked "1" were from a lysimeter which contained no added boron or aluminum. The roots marked "4" were from a lysimeter which contained no

added boron, but aluminum had been added at the rate of 20 pounds per acre. The roots marked "7" were from a lysimeter which contained no added boron, but aluminum had been added at the rate of 40 pounds per acre. The distortion in the roots grown in the presence of 40 pounds of applied aluminum may be the result of an aluminum toxicity reaction.

The yields of the rutabaga tops are presented in Table 9 and Appendix Table 9. Although there were no significant effects from the application of aluminum or boron to the soil, it was apparent that there was an increase in yield due to the addition of boron to the soil. The addition of aluminum to the soil at the rate of 40 pounds per acre, when combined with boron at the rate of 0 pounds per acre, resulted in a decrease in top yields.

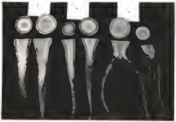
TABLE 9.-Effect of aluminum and boron applied to Blichton fine sand on the weights[1] of rutabaga tops in the second lysimeter test

Pounds/acre of Al applied	Pounds/acre of B applied			Average
	0	1	2	
	g.	g.	g.	g.
0	7.7	8.8	10.7	9.0
20	7.2	10.3	9.8	9.1
40	8.5	9.3	8.5	8.1
Average	7.8	9.5	9.8	8.8

[1]Oven-dry weights

Although there was no significant response shown by the rutabaga tops to treatment, there was a highly significant difference in root weights due to the addition of boron to the soil. The roots from the lysimeters receiving added boron were two times as heavy as the roots from the check plots. There was no significant effect from aluminum applied to the soil.

PLATE I.



RUTABAGA ROOTS SHOWING SYMPTOMS OF BROWN HEART DISEASE CAUSED BY BORON DEFICIENCY

However, the weights of the roots growing in the lysimeters containing aluminum at the rate of 40 pounds per acre and boron at the rate of 8 pounds per acre were drastically reduced. This indicated that there could have been an interaction between aluminum and boron applied to the soil. The yields of rutabaga roots are presented in Table 10 and Appendix Table 10.

TABLE 10.-Effect of aluminum and boron applied to Blichton fine sand on the weights[1] of rutabaga roots in the second lysimeter test

Pounds/acre of Al applied	Pounds/acre of B applied			Average
	0	1	8	
	g.	g.	g.	g.
5	3.7	12.2	15.7	11.2
20	6.3	14.3	14.3	11.7
40	8.8	10.3	8.3	8.4
Average*	6.2	12.4	12.8	10.4

[1]Oven-dry weights

*Least significant difference between boron means at the .05 level is 3.6 grams and at the .01 level is 4.8 grams.

The boron contents of the rutabaga tops are presented in Table 11 and Appendix Table 11. The rates of boron applied to the soil produced highly significant differences in the amounts of boron found in the tops of the rutabagas. The boron contents of the tops grown in the presence of applied boron were two times, or more, the boron contents of the tops grown in the check plots. There was a significant interaction effect between aluminum and boron applied to the soil which could be seen in the increased boron uptake by the rutabaga tops grown in the lysimeters treated with 20 pounds of aluminum per acre and 1 pound of boron per acre.

In contrast to the effect of applied boron on the uptake of boron by the rutabaga tops, there was no significant effect from boron on the

uptake of boron by the roots as shown in Table 12 and Appendix Table 12.

TABLE 11.-Effect of aluminum and boron applied to Blichton fine sand on the uptake of boron by rutabaga tops in the second lysimeter test

Pounds/acre of Al applied	Pounds/acre of B applied			Average
	0	1	2	
	ppm.	ppm.	ppm.	ppm.
0	36**	57	82	58
20	28	78	79	62
40	33	80	78	57
Average[3]	32	65	80	58

**The standard error for these treatment means is ±4.5.

However, there appeared to be a trend for the uptake of boron to increase as the rate of applied boron was increased. This trend was shown by the difference in the uptake of boron from the check plots (no added boron) and from the plots receiving added boron, and by the difference between the plots receiving 1 pound of added boron and those receiving 2 pounds of added boron. There was no significant effect from the application of aluminum to the soil in the uptake of boron by the roots of the rutabaga plants.

The addition of aluminum to the soil did not significantly increase the amount of aluminum taken up by the rutabaga plants in either the tops or the roots. However, there was a significant interaction effect between aluminum and boron. A lower accumulation of aluminum occurred in the plants which had been treated with boron at the rate of 1 pound per acre and aluminum at the rate of 40 pounds per acre than at the other boron levels. Another phase of the interaction was shown only at the highest boron level

[3]In this and subsequent table where Al x B interactions are significant, the least significant differences for boron or aluminum means were not calculated.

where the lowest accumulation of aluminum occurred in the control compared to the highest amount where aluminum was applied at the 40-pound rate. In the absence of applied boron, aluminum uptake was not affected. In other words, there appeared to be no effect from boron applied to the soil which resulted in a general decrease in the amount of aluminum taken up by the rutabaga leaves. A comparison between the aluminum contents of the ruta-

TABLE 12.-Effect of aluminum and boron applied to Blighton fine sand on the uptake of boron by rutabaga roots in the second lysimeter test

Pounds/acre of Al applied	Pounds/acre of B applied			Average
	0	1	2	
	ppm.	ppm.	ppm.	ppm.
0	53	52	49	51
20	41	36	80	59
40	46	63	71	60
Average	47	57	67	57

baga leaves and the roots readily showed that there was a higher accumulation of aluminum in the roots than in the leaves. The aluminum contents of the rutabaga tops and roots are presented in Table 13 and Appendix Table 13 and Table 14 and Appendix Table 14, respectively.

The amounts of calcium found in the rutabaga leaves are presented in Table 13 and Appendix Table 13. There was no significant difference among treatments in the accumulation of calcium by the rutabaga leaves. However, boron applied to the soil had a decided effect on the amounts of calcium found in the rutabaga roots. In the absence of adequate boron there was an accumulation of calcium in the roots as shown by the per root

TABLE 13.-Effect of aluminum and boron applied to Blichton fine sand on the uptake of aluminum by rutabaga tops in the second lysimeter test

Pounds/acre of Al applied	Pounds/acre of B applied			Average
	0	1	2	
	ppm.	ppm.	ppm.	ppm.
0	240**	202	140	194
20	298	198	225	240
40	275	158	383	273
Average	271	186	250	235

**The standard error for these treatment means is ± 175.

TABLE 14.-Effect of aluminum and boron applied to Blichton fine sand on the uptake of aluminum by rutabaga roots in the second lysimeter test

Pounds/acre of Al applied	Pounds/acre of B applied			Average
	0	1	2	
	ppm.	ppm.	ppm.	ppm.
0	785	785	735	770
20	475	905	725	700
40	1095	850	715	890
Average	785	850	725	785

of calcium in the roots; these data are shown in Table 10 and Appendix Table 10. This suggested that there could be no immobilization of calcium in the roots of rutabaga plants in the absence of sufficient boron for normal plant metabolism. The addition of aluminum to the soil had no effect on the uptake of calcium by the rutabaga plants.

Leachates were collected from the individual lysimeters periodically and analyzed for aluminum and boron. The concentration of aluminum was not great enough in any of the leachates to be detected. The total amounts of boron that were leached from the lysimeters during the period of the

TABLE 15.-Effect of aluminum and boron applied to Blichton fine sand on the uptake of calcium by rutabaga tops in the second lysimeter test

Pounds/acre of Al applied	Pounds/acre of B applied			Average
	0	1	2	
	%	%	%	%
0	.31	.33	.30	.34
20	.32	.31	.33	.32
40	.30	.37	.35	.34
Average	.33	.34	.35	.34

TABLE 16.-Effect of aluminum and boron applied to Blichton fine sand on the uptake of calcium by rutabaga roots in the second lysimeter test

Pounds/acre of Al applied	Pounds/acre of B applied			Average
	0	1	2	
	%	%	%	%
0	.49	.20	.30	.30
20	.35	.23	.33	.36
40	.45	.35	.40	.40
Average*	.49	.20	.31	.37

*Least significant difference between boron means at the .05 level is 0.13 per cent and at the .01 level is 0.17 per cent.

test are presented in Table 17 and Table 17 of the Appendix. The effect of the rates of boron added to the soil produced a highly significant difference in the amounts of boron leached from the lysimeters. The amount of boron leached from the lysimeters receiving no added boron was not significantly different from the amount of boron leached from the lysimeters treated with 1 pound of boron. However, the amount of boron leached from the lysimeters treated with 2 pounds of boron differed greatly from the amount of boron leached from either of the other boron treatments. The application of aluminum to the soil had no effect on the amount of boron leached from the ly-

simeters.

TABLE 17.-Effect of aluminum and boron applied to Blichton fine sand on the total amounts of boron in lysimeter leachates from rutabagas in the second lysimeter test

Pounds/acre of Al applied	Pounds/acre of B applied			Average
	0	1	2	
	mg.	mg.	mg.	mg.
0	0.85	1.69	2.35	1.63
20	1.00	1.19	2.82	1.69
40	1.27	1.48	3.07	1.94
Average*	1.00	1.48	2.75	1.75

*Least significant difference between boron means at the .05 level is 0.83 milligrams and at the .01 level is 0.07 milligrams.

The results of this test showed that the Blichton fine sand used in the lysimeters was sufficiently low in cation available boron to result in a marked response by rutabaga plants to added boron. The plants growing in the absence of applied boron rapidly developed signs of boron deficiency. In contrast, aluminum had very little effect on growth, although there was an interaction between aluminum and boron which resulted in a lowered uptake of both aluminum and boron by the rutabaga tops.

<u>Lettuce test</u>

There was an early appearance of boron deficiency symptoms in the lettuce plants. Boron deficiency symptoms in lettuce (63) appeared as a curling over and under of the leaves of the growing tip. The leaves turned dark brown along the margins, presenting a scorched appearance. Lettuce plants grown in all of the lysimeters receiving no added boron were affected by boron deficiency symptoms.

The yield data of the lettuce plants are presented in Table 18 and

Appendix Table 18. There was no significant difference in the weights due to applied boron, but there were significant differences due to applied aluminum and to an aluminum and boron interaction. This interaction was shown by the fact that the lowest yield of 2.1 grams from the plots receiving 40 pounds of aluminum per acre and no added boron was significantly different from the other yields according to Duncan's shortest significant range test. The three next lowest yields from high aluminum and boron rates were also significantly different from the other yields. Lettuce has been shown to be highly sensitive to aluminum toxicity (22). However, the lettuce plants in this test exhibited no recognizable symptoms of aluminum toxicity. This could have been because of the aluminum and boron interaction effect, or it could have been possible that the signs of aluminum toxicity were obscured by the signs of boron deficiency. The lowest yield of lettuce was from the lysimeters which had received 40 pounds of aluminum per acre and no added boron. The addition of boron to the soil reduced this effect of aluminum on yield to a large extent, as can be seen by the yields of lettuce from the lysimeters which had received 40 pounds of aluminum per acre and applied boron. The yields were doubled where boron had been applied in conjunction with the high rate of aluminum as compared with the absence of applied boron.

There was a highly significant difference due to boron applications in the uptake of boron by lettuce plants (Table 19 and Appendix Table 19). The uptake of boron by the seedlings growing in the presence of 1 and 2 pounds of applied boron was over twice the uptake from the check plots. The difference between the uptake of boron from the lysimeters which had received 1 pound of boron per acre and those which had received 2 pounds

TABLE 10.-Effect of aluminum and boron applied to Blichton fine sand on the weights[a] of lettuce plants in the second lysimeter test

Pounds/acre of Al applied	Pounds/acre of B applied			Average*
	0	1	2	
	g.	g.	g.	g.
0	4.0	4.7	5.6	5.0
20	6.0	4.0	4.0	4.7
40	2.1	4.0	4.5	3.5
Average	4.3	4.3	4.7	4.4

[a]Oven-dry weights

*Least significant difference between aluminum means at the .05 level is 1.0 gram and at the .01 level is 1.4 grams.

of boron per acre was also significant. The surprising aspect of this test was that aluminum had a highly significant effect on the uptake of boron, which resulted in the amount of boron absorbed by the lettuce increasing as the levels of applied aluminum increased. The highest content of boron occurred in the lettuce plants grown in the lysimeters which had been treated with 0 pounds of boron per acre and 40 pounds of aluminum per acre.

TABLE 11.-Effect of aluminum and boron applied to Blichton fine sand on the uptake of boron by lettuce plants in the second lysimeter test

Pounds/acre of Al applied	Pounds/acre of B applied			Average*
	0	1	2	
	ppm.	ppm.	ppm.	ppm.
0	18	50	64	44
20	27	40	60	43
40	27	72	80	60
Average*	24	57	68	50

*Least significant difference between aluminum and boron means at the .05 level is 9 ppm. and at the .01 level is 13 ppm.

It is logical to assume that lettuce, which showed a sensitivity to aluminum toxicity of an order sufficient to depress vegetative growth, would accumulate aluminum in the presence of applied aluminum. This, however, was not true in this test, as is shown in Table 20 and Table 20 of the Appendix. There was no significant difference in the uptake of aluminum among the treatments from applied aluminum or applied boron. However, it was interesting to note that lettuce accumulated a larger amount of aluminum in the vegetative parts than the other plant species in these tests. This phenomenon may be one reason for the sensitivity of lettuce to aluminum toxicity.

TABLE 20.-Effect of aluminum and boron applied to Blichton fine sand on the uptake of aluminum by lettuce plants in the second lysimeter test

Pounds/acre of Al applied	Pounds/acre of B applied			Average
	0	1	2	
	ppm.	ppm.	ppm.	ppm.
0	410	470	510	460
20	480	520	480	480
40	480	440	500	490
Average	440	420	470	470

Although the aluminum treatments did not significantly influence the amount of aluminum absorbed by lettuce, there was a highly significant effect on the amount of calcium found in the lettuce as shown in Table 21 and Table 21 of the Appendix. Here aluminum had a depressing effect on the uptake of calcium, i.e., the percentage of calcium was high in the lettuce from the lysimeters receiving no added aluminum and decreased as the rate of aluminum applied to the soil increased. This corroborated the finding of Schmehl et al. (35) that aluminum interfered with the absorption of

calcium-45, from nutrient solution, by alfalfa. The reason for this effect of aluminum on the uptake of calcium by lettuce was not clear, but it could be due to the sensitivity of lettuce to aluminum toxicity.

TABLE 21.-Effect of aluminum and boron applied to Blichton fine sand on the uptake of calcium by lettuce in the second lysimeter test

Pounds/acre of Al applied	Pounds/acre of B applied			Average[a]
	0	1	2	
	%	%	%	%
0	.13	.13	.14	.13
20	.13	.13	.13	.13
40	.11	.13	.12	.12
Average	.13	.13	.13	.13

[a]Least significant difference between aluminum means at the .05 level is 0.01 per cent and at the .01 level is 0.02 per cent.

As in the other lysimeter tests, leachates were collected periodically and analyzed for aluminum and boron. Once again the levels of aluminum were not great enough to be detectable in the leachates. All of the samples analyzed for aluminum read the same as the blank in the colorimeter. The total amounts of boron that were leached from the lysimeters are presented in Table 22 and Table 22 of the Appendix. There was a highly significant difference among treatments in the amount of boron leached due to the rates of boron applied to the soil. In this test the difference between each boron treatment was significant according to the least significant difference test.

The results of this test confirmed that lettuce was a sensitive plant species with respect to aluminum toxicity. It was a much heavier accumulator of aluminum than either rutabaga or sunflower plants. The fact that lettuce was an accumulator of aluminum could be the reason for its

sensitivity to aluminum. However, there was no greater accumulation of aluminum from the plots receiving added aluminum than from the check plots. On the other hand, applied aluminum had a pronounced effect on the uptake of boron by the lettuce plants, i.e., there was an increase in boron content as the amount of aluminum applied to the soil increased.

TABLE 22.-Effect of aluminum and boron applied to Blichton fine sand on the total amounts of boron in lysimeter leachates from lettuce in the second lysimeter test

Pounds/acre of Al applied	Pounds/acre of B applied			Average
	0	1	2	
	mg.	mg.	mg.	mg.
0	0.54	1.92	3.64	0.04
20	0.70	1.91	3.62	2.10
40	1.08	1.70	2.46	1.77
Average*	0.90	1.98	3.25	1.98

*Least significant difference between boron means at the .05 level is 0.92 milligram and at the .01 level is 1.10 milligrams.

The reason for this facet of the behavior of lettuce was not clear, but it could have been an effect from the toxic aspect of aluminum. The effect on the boron content is that as rates of aluminum applied to the soil were increased, there was a decrease in the per cent of calcium in the lettuce plants.

Clover test

The third crop grown in the second lysimeter test was Louisiana S-1 white clover. Boron deficiency symptoms were late in developing, but within a short time of the appearance of the first affected leaves, all of the clover growing in the lysimeters which had received no added boron was se-

hibiting signs of boron deficiency. Symptoms of boron deficiency in clover were quite different from like symptoms in vegetables. In this white clover there was first a light purplish red color along the margins of affected leaves. This color spread towards the center of the leaf and as it spread, it became a darker red. Within a short time the entire leaf was colored a dark purplish red which persisted for varying lengths of time, until the leaf turned brown and was dead. Plate II is a color picture of boron deficient clover in this test. This picture shows two of the lysimeters used in this test, with healthy clover in the lysimeter numbered 3 which had been treated with 2 pounds of boron per acre and no aluminum, and boron deficient clover in the lysimeter numbered 4 which had been treated with no boron and 20 pounds of aluminum per acre. The discolored leaves in the boron deficient clover were symptoms of the lack of boron in the plants.

The yield data of white clover are presented in Table 23 and Table 23 of the Appendix. There was a highly significant difference in yields due to the addition of aluminum to the soil. The yields from the check plots, which received no aluminum treatment, were significantly greater than the yields from the plots receiving added aluminum. There was also a significant difference in clover yields due to the addition of boron to the soil. The yields from the plots receiving added boron were significantly greater than the check plots, which received no added boron. There was no significant effect on yields due to an interaction between aluminum and boron.

The application of boron to the soil produced a highly significant increase in the amount of boron absorbed by the clover as shown in Table

PLATE II

LOUISIANA S-1 WHITE CLOVER SHOWING SYMPTOMS OF BORON DEFICIENCY

TABLE 23.-Effect of aluminum and boron applied to Blanton fine sand on the weights[1] of white clover in the second lysimeter test

Pounds/acre of Al applied	Pounds/acre of B applied			Average*
	0	1	2	
	g.	g.	g.	g.
0	21.3	24.8	24.7	23.5
20	16.3	23.7	21.5	19.8
40	18.8	20.0	17.0	18.8
Average*	18.8	22.8	21.0	21.0

[1]Oven-dry weights

*Least significant difference between aluminum and boron means at the .05 level is 2.7 grams and at the .01 level is 3.6 grams.

24 and Appendix Table 24. The uptake of boron by the clover growing in the lysimeters receiving added boron was over twice the uptake of boron from the check plots. Attention is called to the fact that the clover from the boron check plots averaged 22 ppm. boron content. Although it has been difficult to set a lower limit of boron content in a plant species at which the plant was deficient in boron, it could be postulated that Louisiana S-1 white clover was deficient in boron when it contained as low as 22 ppm. boron. The application of aluminum to the soil produced no significant effect on the ability of the clover to obtain boron from the soil.

The aluminum contents of the white clover are presented in Table 25 and Table 21 of the Appendix. It was readily seen that white clover was a relatively heavy accumulator of aluminum as compared to the other crops in the lysimeter tests. This fact was also borne out by the decrease in yield due to applied aluminum as shown in Table 23. In this respect white clover could be classed with lettuce as an aluminum sensitive plant species. However, there were no significant differences among treatments, due to aluminum or boron, in the uptake of aluminum by the clover. Although boron

produced no significant difference in the aluminum content of the clover, there seemed to be a slight trend for the amount of aluminum to decrease as the rates of applied boron increased.

TABLE 24.-Effect of aluminum and boron applied to Blichton fine sand on the uptake of boron by white clover in the second lysimeter test

Pounds/acre of Al applied	Pounds/acre of B applied			Average
	0	1	2	
	ppm.	ppm.	ppm.	ppm.
0	22	53	52	42
20	26	45	53	39
40	24	53	51	43
Average*	22	50	52	41

*Least significant difference between boron means at the .25 level is 5 ppm. and at the .01 level is 6 ppm.

TABLE 25.-Effect of aluminum and boron applied to Blichton fine sand on the uptake of aluminum by white clover in the second lysimeter test

Pounds/acre of Al applied	Pounds/acre of B applied			Average
	0	1	2	
	ppm.	ppm.	ppm.	ppm.
0	360	310	250	300
20	240	200	170	200
40	240	200	190	270
Average	280	240	200	260

The calcium contents of the clover are presented in Table 26 and Table 26 of the Appendix. The addition of aluminum and boron to the soil produced no significant differences in the uptake of calcium by the clover. It was of interest to note that the white clover in this test contained the highest percentage of calcium of any of the crops used in these tests.

TABLE 26.-Effect of aluminum and boron applied to Blichton fine sand on the uptake of calcium by white clover in the second lysimeter test

Pounds/acre of Al applied	Pounds/acre of B applied			Average
	0	1	2	
	%	%	%	%
0	.57	.62	.71	.64
20	.66	.59	.62	.62
40	.62	.72	.66	.67
Average	.62	.64	.66	.64

In order to ascertain the amounts of aluminum and boron leached from the lysimeters sustaining white clover the leachates were collected and analyzed for aluminum and boron. As in the previous lysimeter tests, aluminum was not of sufficient amounts in the leachates to be detectable. The amounts of boron lost from the soil through leaching are presented in Table 27 and Appendix Table 27. There was a highly significant difference in the amounts of boron in the leachates due to the rates of boron applied to the soil. The total boron removed from the smaller lysimeters containing clover in this test was greater than the total boron removed from the larger lysimeters containing lettuce or rutabagas because the clover was growing in the lysimeters for a longer period of time and, therefore, more water percolated through the lysimeters sustaining clover.

It could be concluded from the results of this test that both aluminum and boron influenced the yields of Louisiana S-1 white clover. In the case of aluminum, there was a marked reduction in the yield of clover from the application of aluminum to the soil. In this respect, and as white clover absorbs relatively large amounts of aluminum, this species could be classified as aluminum sensitive. In contrast to aluminum, there

TABLE 27.-Effect of aluminum and boron applied to Elkton fine sand on the total amounts of boron in lysimeter leachates from white clover in the second lysimeter test

Pounds/acre of Al applied	Pounds/acre of B applied			Average
	0	1	2	
	mg.	mg.	mg.	mg.
0	0.96	2.03	4.00	2.34
20	0.50	2.09	4.33	2.33
40	0.77	1.54	4.13	2.14
Average*	0.74	1.89	4.16	2.26

*Least significant difference between boron means at the .05 level is 0.70 milligram and at the .01 level is 1.04 milligrams.

was no increase in yield due to boron applied to the soil over the yield of clover from the check plots. Boron applied to the soil resulted in a very large increase in the uptake of boron by white clover. Aluminum had no effect on the uptake of boron by the clover. There was no effect from aluminum or boron on the absorption of calcium from the soil.

Solution Culture Experiment

First solution culture test

This test was conducted in the greenhouse with sunflower plants, grown in nutrient solution, as the indicator plants. The sunflower plants grown in the jars containing no added boron developed boron deficiency symptoms within four days, or less, of being placed in the nutrient solution. These symptoms grew progressively worse as the plants aged and by the time they were harvested, the growing tips were dead and the other parts of the plants were suffering severely from the lack of boron. It was quite apparent that the lack of sufficient boron in the nutrient of the plants resulted in a drastic reduction of plant growth. The effect

of aluminum on the growth of the sunflower plants was not noticeable at any time during the period of this test.

The effect of a deficient supply of boron on the growth of the sunflower plants may be seen by comparing the plants shown in Plate III. The small plants in the jars marked Trt. I, Trt. IV, and Trt. VII are in nutrient solution containing no added boron in which they have been growing for approximately four weeks. The lack of an effect from aluminum may be seen by comparing the plants in the jars marked Trt. I, Trt. II, and Trt. III, which contain no added aluminum, to the plants in the jars marked Trt. IV, Trt. V, and Trt. VI, which contain 0.5 ppm. of aluminum, or to the plants marked Trt. VII, Trt. VIII, and Trt. IX, which contain 1.0 ppm. of aluminum. The last two jars in each of the three series above contain 0.5 ppm. and 1.0 ppm. of boron, respectively, which explains the better growth.

The pH of the original nutrient solution was 5.2 before the addition of either aluminum or boron. In Table 28 are presented the pH values for the nutrient solutions at the time of discard after one week of supporting plant growth. It was obvious that boron in the solution had a tendency to increase the pH of the solution. Aluminum, on the other hand, tended to decrease the pH of the solution.

The yield data of the sunflower tops are presented in Table 29 and Table 28 of the Appendix. As could be expected because of the low levels of boron in the glassware and chemicals, there was a highly significant difference among treatments due to the rates of boron added to the solution cultures. By applying the least significant difference test among the means of the boron levels it may be seen that the difference between the 0 level of

PLATE III

SUNFLOWER PLANTS IN NUTRIENT SOLUTION SHOWING EFFECTS OF ALUMINUM AND BORON IN THE SOLUTION

TABLE 28.-The pH[1] of the nutrient solution cultures when discarded after one week of plant use

Treatment		Dates on which solution cultures were changed			
Al	B	Nov. 9	Nov. 16	Nov. 23	Nov. 29
ppm.	ppm.	pH	pH	pH	pH
0	0	5.2	5.4	5.4	5.6
0	0.5	5.7	5.7	5.8	5.9
0	1.0	5.8	5.8	5.9	6.0
0.5	0	5.0	5.2	5.0	5.2
0.5	0.5	5.5	5.4	5.4	5.5
0.5	1.0	5.4	5.5	5.5	5.6
1.0	0	5.0	5.0	4.9	4.7
1.0	0.5	5.4	5.4	5.5	5.4
1.0	1.0	5.5	5.5	5.5	5.4

[1]Average of four replications

added boron and the 0.5 and 1.0 ppm. levels was significant. The difference between the 0.5 ppm. level of boron and the 1.0 ppm. level of boron was also significant. The greatest yield of sunflower tops was from the jars containing 1.0 ppm. of boron. The effect from aluminum in solution was not significant under these conditions.

TABLE 29.-Effect of aluminum and boron in nutrient solution culture on the weights[1] of sunflower tops in the first solution culture test

Aluminum added	Boron added, ppm.			Average
	0	0.5	1.0	
ppm.	g.	g.	g.	g.
0	0.40	0.17	3.34	1.64
0.5	0.55	1.95	2.80	1.69
1.0	0.40	0.05	2.51	1.95
Average*	0.50	0.05	0.58	1.66

[1]Oven-dry weights

*Least significant difference between boron means at the .05 level is 0.42 gram and at the .01 level is 0.58 gram.

The weights of sunflower roots as shown in Table 30 and Table 29 of the Appendix, followed the same trend as the weights of the tops in that a highly significant difference among the weights of the roots occurred at the three rates of boron in the solution. The difference, according to the least significant difference test, was significant between any two levels of boron in solution. The greatest yield of roots was from the jars containing 1.0 ppm. of boron in solution. There was no difference among the root weights due to aluminum in solution.

TABLE 30.-Effect of aluminum and boron in nutrient solution culture on the weights[1] of sunflower roots in the first solution culture test

Aluminum added	Boron added, ppm.			Average
	0	0.5	1.0	
ppm.	g.	g.	g.	g.
0	.13	.51	.48	.37
0.5	.11	.43	.63	.39
1.0	.12	.41	.57	.39
Average*	.12	.45	.56	.39

[1]Oven-dry weights

*Least significant difference between boron means at the .05 level is 0.20 gram and at the .01 level is 0.14 gram.

The presence of boron in the nutrient solution effected a highly significant increase in the heights of the sunflower plants, as shown in Table 31 and Table 30 of the Appendix. The plants grown in the absence of boron were only about one-fourth as high as the plants grown in the presence of boron in solution. The difference in height between the plants grown in solution containing 0.5 ppm. of boron and those grown in solution containing 1.0 ppm. of boron was not significant according to the least significant difference test. The presence or absence of aluminum in the nutrient solu-

tion had no significant effect on the height of the sunflower plants.

TABLE 31.-Effect of aluminum and boron in nutrient solution culture on the heights of sunflower plants in the first solution culture test

Aluminum added	Boron added, ppm.			Average
	0	0.5	1.0	
ppm.	in.	in.	in.	in.
0	4.50	12.12	12.46	8.65
0.5	3.37	14.07	14.70	10.65
1.0	3.75	15.50	14.00	11.05
Average*	3.84	14.20	15.70	10.75

*Least significant difference between boron means at the .05 level is 2.22 inches and at the .01 level is 3.20 inches.

The boron contents of the sunflower tops are presented in Table 32 and Table 31 of the Appendix. The effect from boron in solution was highly significant in the uptake of boron among treatments; however, the difference between the 0.5 ppm. and the 1.0 ppm. of boron in solution was not significant. There was, in fact, a decrease in uptake from the solution containing 1.0 ppm. of boron as compared to the uptake from the solution containing 0.5 ppm. of boron, but the difference was not significant. Although there was no significant effect from the presence of aluminum in the solution on the uptake of boron by the sunflower tops, there was a consistent trend for the uptake of boron to increase in the presence of added aluminum.

There was no significant difference among treatments in the uptake of boron by the sunflower roots (Table 33 and Appendix Table 32). Although the presence of boron in the solution had no significant effect, there appeared to be a trend for the boron content of the roots to increase with increasing rates of boron in solution.

TABLE 32.–Effect of aluminum and boron in nutrient solution culture on the uptake of boron by sunflower tops in the first solution culture test

Aluminum added	Boron added, ppm.			Average
	0	0.5	1.0	
ppm.	ppm.	ppm.	ppm.	ppm.
0	77	205	192	158
0.5	113	237	220	193
1.0	108	212	198	174
Average*	100	528	206	174

*Least significant difference between boron means at the .05 level is 40 ppm. and at the .01 level is 55 ppm.

TABLE 33.–Effect of aluminum and boron in nutrient solution culture on the uptake of boron by sunflower roots in the first solution culture test

Aluminum added	Boron added, ppm.			Average
	0	0.5	1.0	
ppm.	ppm.	ppm.	ppm.	ppm.
0	406	433	406	415
0.5	369	350	487	406
1.0	238	480	438	385
Average	339	428	478	415

The aluminum contents of the sunflower tops are presented in Table 34 and Table 55 of the Appendix. Significant difference in the uptake of aluminum among treatments were not obtained. There was a trend for the amount of aluminum found in the tops to decrease in the presence of boron in the solution. This may be verified by observing that the sunflower plants growing in the absence of boron contained 76 ppm. of aluminum in the tops, while the plants growing in the presence of 0.5 ppm. and 1.0 ppm. of boron contained only 40 ppm. and 55 ppm. of aluminum, respectively. Although statistically there was no difference in the uptake of alu-

minum due to boron, it was of interest to note that the "F" value for boron (Appendix Table 53), calculated to be 3.18, was very close to the "F" value of 3.40 required for significance at the 5 per cent level.

TABLE 34.-Effect of aluminum and boron in nutrient solution culture on the uptake of aluminum by sunflower tops in the first solution culture run

Aluminum added	Boron added, ppm.			Average
	0	0.5	1.0	
ppm.	ppm.	ppm.	ppm.	ppm.
0	50	41	72	55
0.5	80	40	43	54
1.0	88	40	51	63
Average	76	40	55	58

In contrast to the aluminum contents of the sunflower tops, it was interesting to compare the aluminum contents of the sunflower roots (Table 35 and Table 54 of the Appendix). The effect of aluminum in the solution was highly significant on the uptake of aluminum by the roots. The differences between any two of the three means for aluminum was significant according to the least significant difference test. The high amounts of aluminum found in the roots supported the observation of McLean and Gilbert (44) that aluminum accumulated in the root systems of plants and was not translocated to the vegetative organs. The low aluminum content of the leaves versus the high aluminum content of the roots was also evidence of this fact.

Boron in the nutrient solution exerted a highly significant effect on the uptake of calcium by the sunflower tops as shown in Table 80 and Appendix Table 55. In the absence of boron there was a drastic reduction in the calcium content of the vegetative parts of the sunflower plants. The difference between the two levels of boron in the solution was also signif-

TABLE 35.-Effect of aluminum and boron in nutrient solution culture on the uptake of aluminum by sunflower roots in the first solution culture test

Aluminum added	Boron added, ppm.			Average*
	0	0.5	1.0	
ppm.	ppm.	ppm.	ppm.	ppm.
0	1190	400	370	653
0.5	3070	3010	4370	3480
1.0	7540	9850	8280	8560
Average	3930	4430	4400	4230

*Least significant difference between aluminum means at the .05 level is 2360 ppm. and at the .01 level is 3210 ppm.

icant according to the least significant difference test. The extremely high calcium percentage, 6.00, in the sunflower tops grown in the presence of 1.0 ppm. of boron and 1.0 ppm. of aluminum cannot be explained. The addition of aluminum to the solution cultures had no statistically significant effect on the percentage of calcium found in the sunflower tops.

TABLE 36.-Effect of aluminum and boron in nutrient solution culture on the uptake of calcium by sunflower tops in the first solution culture test

Aluminum added	Boron added, ppm.			Average
	0	0.5	1.0	
ppm.	%	%	%	%
0	0.40	3.14	3.20	2.25
0.5	0.45	1.17	3.24	1.63
1.0	0.29	1.41	6.00	2.65
Average*	0.38	1.99	4.15	2.17

*Least significant difference between boron means at the .05 level is 1.21 per cent and at the .01 level is 1.63 per cent.

In agreement with the calcium contents of the sunflower tops, there was a highly significant difference in the calcium contents of the sunflower roots which may be seen in Table 37 and Appendix Table 36. However,

this difference in calcium uptake by the roots was not as pronounced as the difference in calcium uptake by the tops. The application of the least significant difference test shows that the difference was between the lowest level of boron in solution and the 0.5 ppm. and 1.0 ppm. levels of boron, but not between the two levels of applied boron. Again in agreement with the sunflower tops, calcium content was not altered by the presence of aluminum in the solution cultures.

TABLE 37.-Effect of aluminum and boron in nutrient solution culture on the uptake of calcium by sunflower roots in the first solution culture test

Aluminum added	Boron added, ppm.			Average
	0	0.5	1.0	
ppm.	%	%	%	%
0	.10	.04	.03	.07
0.5	.08	.03	.04	.05
1.0	.06	.04	.06	.05
Average*	.08	.04	.03	.06

*Least significant difference between boron means at the .05 level is 0.016 per cent and at the .01 level is .022 per cent.

It may be concluded from the results of the first solution culture test that the presence of boron in the nutrient solution exerted a tremendous influence on the weight of the sunflower roots and vegetative parts. There was also a drastic reduction in the height of the sunflower plants when boron was not present in the nutrient solution. The uptake of boron from the solution by the sunflower tops was greatly increased when boron was supplied, but there was no significant increase in the uptake of boron by the roots. In the absence of boron from the nutrient solution there were large decreases in the uptake of calcium by the tops and by the roots

of the sunflower plants. This was in agreement with the findings of Henderson and Veal (30) and Minarik and Shive (46) that the presence of boron in nutrient solution produced a large increase in the absorption of calcium by blue lupine and soybean plants, respectively.

In contrast to boron, aluminum had no effect on the heights and weights of the sunflower plants or on the uptake of boron and calcium by the plants. However, increasing rates of aluminum in solution resulted in very large increases in the accumulation of aluminum in the roots of the sunflower plants. This fact substantiates the findings of McLean and Gilbert (44) that aluminum accumulated in the roots of plants. The contents of aluminum in sunflower tops were not increased by the presence of aluminum in the solution. The lack of aluminum toxicity signs in the sunflower plants indicated that the levels of added aluminum were too low to induce toxic effects.

Second solution culture test

The pH values of the nutrient solutions used in this test were not determined because of the similarity between the first solution culture test and the second solution culture test. It was assumed that there should have been no greater increase in the pH of the solutions than there was in the first solution culture test, especially as there was no increase in the aluminum concentration of the solutions in which aluminum was present.

During the first two weeks of the plant growth in the culture jars the intensity of light was very low, because almost continuous cloudy weather prevailed. In order to furnish sufficient light for proper growth

artificial light was provided for about three hours each day, from a row of 200 watt electric light bulbs.

Boron deficiency symptoms were not as rapid in developing in the sunflower plants as in the first solution culture test. The first boron deficiency signs appeared in the sunflower plants growing in solution containing neither added aluminum nor boron. These signs appeared approximately ten days after the plants were transferred to the solution culture jars. The remainder of the plants growing in the absence of boron developed boron deficiency signs shortly thereafter. At the time of harvest all of the sunflower plants that had been in the jars without added boron were suffering severely from the lack of boron.

The yield data of the sunflower tops are presented in Table 38 and Appendix Table 37. The addition of boron to the solution culture resulted in a highly significant difference among treatments. According to the least significant difference test, the yield from the jars containing no boron was significantly different from the yields of the jars containing boron. It was surprising that the yield of the jars containing 1.0 ppm. of boron was significantly less than the yield of the jars containing 0.5 ppm. of boron. This decrease in yield was caused by the low yields of the jars containing added aluminum, although the effect from aluminum was not significant.

There was a highly significant difference among root weights where boron was added to the solution culture, but this difference was not great enough to distinguish between the root weights produced by the 0.5 ppm. level of boron and the 1.0 ppm. level. The yields of sunflower roots was presented in Table 39 and Appendix Table 38. The presence of aluminum in the solution did not exert a significant influence on the weights of the

TABLE 29.-Effect of aluminum and boron in nutrient solution culture on the weights[1] of sunflower tops in the second solution culture test

Aluminum added	Boron added, ppm.			Average
	0	0.5	1.0	
ppm.	g.	g.	g.	g.
0	1.1	9.3	9.5	6.6
1	2.2	9.1	6.7	6.0
2	1.9	9.0	7.7	6.2
Average*	1.6	9.0	8.0	6.3

[1]Oven-dry weights

*Least significant difference between boron means at the .05 level is 1.09 grams and at the .01 level is 1.43 grams.

sunflower roots. However, there was a decrease in root weights from the jars containing 1 ppm. of boron and 1 and 2 ppm. of aluminum. The general decrease in sunflower top and root yields from these two treatments indicated a trend caused by aluminum and boron interaction.

TABLE 30.-Effect of aluminum and boron in nutrient solution culture on the weights[1] of sunflower roots in the second solution culture test

Aluminum added	Boron added, ppm.			Average
	0	0.5	1.0	
ppm.	g.	g.	g.	g.
0	0.27	2.03	2.04	1.46
1	0.61	2.04	1.67	1.44
2	0.50	2.00	1.58	1.30
Average*	0.47	2.03	1.76	1.41

[1]Oven-dry weights

*Least significant difference between boron means at the .05 level is 0.37 gram and at the .01 level is 0.50 gram.

The presence of boron in the solution culture resulted in a highly significant difference in the heights of the sunflower plants as can be

seen in Table 40 and Appendix Table 39. There was a significant difference between the heights of the plants grown in the absence of boron from the solution culture and the plants grown in the presence of boron. However, there was no difference in height between the two levels of boron in solution. There was no significant effect from aluminum additions, but there was a highly significant difference in plant height due to an interaction between aluminum and boron. This interaction resulted in no apparent decrease in the average height of the plants grown in the presence of 0.5 ppm. of boron and 2 ppm. of aluminum and in the average height of the plants grown in the presence of 1 ppm. of boron and 1 ppm. of aluminum. The interaction was also there in no increase in the average height of the plants grown in solution containing no boron and 1 ppm. of aluminum. The greatest average height of the sunflower plants was in the plants grown in solution containing 0.5 ppm. of boron and 1 ppm. of aluminum.

TABLE 40.-Effect of aluminum and boron in nutrient solution culture on the heights of sunflower plants in the second solution culture test

Aluminum added	Boron added, ppm.			Average
	0	0.5	1.0	
ppm.	in.	in.	in.	in.
0	13.25**	35.00	34.25	27.50
1	19.50	36.75	31.50	29.50
2	15.25	31.00	34.25	26.75
Average	19.00	34.25	33.25	28.25

**The standard error for these means is $\pm$ 1.35.

The boron contents of the sunflower tops are shown in Table 41 and Table 80 of the Appendix. As could be expected, the effect of added boron

in the nutrient solution was highly significant. A significant difference was shown in the uptake of boron by the sunflower tops from each of the three levels of boron in the solution cultures. The presence of aluminum in the solution had no apparent influence on the ability of the sunflower tops to obtain boron. There was not, apparently, an interaction between aluminum and boron in the solution cultures that had appreciable effect on the uptake of boron.

TABLE 41.-Effect of aluminum and boron in nutrient solution culture on the uptake of boron by sunflower tops in the second solution culture test

Aluminum added	Boron added, ppm.			Average
	0	0.5	1.0	
ppm.	ppm.	ppm.	ppm.	ppm.
0	73	80	100	85
1	79	76	97	84
2	60	89	99	83
Average*	71	81	99	84

*Least significant difference between boron means at the .05 level is 15 ppm. and at the .01 level is 22 ppm.

The boron contents of the sunflower roots are presented in Table 42 and Appendix Table 41. There was a highly significant difference among treatments due to boron; however, in this instance, the roots grown in the absence of added boron contained the higher amounts of boron. This can only be explained by the fact that the roots could have contained relatively large amounts of boron when placed in the nutrient solution and the boron was not translocated to the vegetative parts. By referring to the root weights in Table 38 it can be seen that there probably was very little growth of the roots and any boron present orginally was still in the roots

at the time of harvest. This was evidence of an immobilization of boron in the roots in the absence of boron added to the nutrient solution.

The total amounts of boron removed by the sunflower roots are shown in Table 63. These totals were derived by multiplying the weight of the roots in grams by the uptake of boron in ppm. By applying the least significant difference test, the difference between the uptake of boron by the roots from the solutions at the lowest level of boron and the uptake by the roots from the solutions containing 0.5 and 1.0 ppm. of boron was significant. As was stated above, the roots grown in the absence of boron showed the greatest uptake of boron. However, with respect to the total amounts of boron removed, the roots grown in the presence of boron were far superior to the roots grown in the absence of boron. Aluminum had no significant effect on boron uptake by the roots.

TABLE 62.-Effect of aluminum and boron in nutrient solution culture on the uptake of boron by sunflower roots in the second solution culture test

Aluminum added	Boron added, ppm.			Average
	0	0.5	1.0	
ppm.	ppm.	ppm.	ppm.	ppm.
0	275	164	177	205
1	225	156	220	184
2	242	172	177	200
Average*	250	164	174	195

*Least significant difference between boron means at the .05 level is 38 ppm. and at the .01 level is 52 ppm.

The presence of boron in the nutrient solution exerted a highly significant effect on the uptake of aluminum by the sunflower tops as shown in Table 64 and Appendix Table 42. The uptake of aluminum by the

TABLE 43.-The total amounts of boron removed by sunflower roots in the second solution culture test

Aluminum added	Boron added, ppm.			Average
	0	0.5	1.0	
ppm.	mg.	mg.	mg.	mg.
0	76	336	362	255
1	144	312	276	243
2	126	345	269	247
Average*	116	330	303	250

*Least significant difference between boron means at the .05 level is 163 milligrams and at the .01 level is 222 milligrams.

plants grown in the absence of boron from the nutrient solution was almost twice the uptake of aluminum by the plants grown in solution containing boron. The same effect from boron was almost significant statistically with respect to the uptake of aluminum by the sunflower tops in the first solution culture test. Aluminum added to the solution cultures had no significant effect on the uptake of aluminum by the sunflower tops in this test, as was true in the previous test.

TABLE 44.-Effect of aluminum and boron in nutrient solution culture on the uptake of Aluminum by sunflower tops in the second solution culture test

Aluminum added	Boron added, ppm.			Average
	0	0.5	1.0	
ppm.	ppm.	ppm.	ppm.	ppm.
0	43	20	21	28
1	33	20	24	20
2	28	23	26	29
Average*	39	21	24	28

*Least significant difference between boron means at the .05 level is 8 ppm. and at the .01 level is 10 ppm.

In contrast to the uptake of aluminum by the sunflower tops, the presence of added aluminum in the nutrient solution had a great influence on the absorption of aluminum by the sunflower roots. The data on the aluminum contents of the sunflower roots are presented in Table 43 and Appendix Table 43. There were highly significant differences in aluminum uptake by the roots among treatments due to the levels of aluminum and the levels of boron. The presence of boron in the nutrient solution greatly reduced the amount of aluminum taken up by the roots, while the presence of added aluminum in the solution resulted in large increases in the uptake of aluminum. There was also a highly significant difference in the uptake of aluminum by the roots as the result of an interaction between aluminum and boron. The highest uptake of aluminum of all treatments was by the sunflower roots grown in the solution culture containing no boron and 2 ppm. of aluminum, and the lowest uptake was by the roots grown in solution culture containing no added aluminum.

TABLE 43.--Effect of aluminum and boron in nutrient solution culture on the uptake of aluminum by sunflower roots in the second solution culture test

Aluminum added	Boron added, ppm.			Average
	0	0.3	1.0	
ppm.	ppm.	ppm.	ppm.	ppm.
0	570**	200	180	315
1	1880	1200	1700	1590
4	6200	2100	2800	3730
Average	2900	1160	1580	1880

**The standard error for these means is ± 380.

Aluminum in the nutrient solution had a highly significant effect on the uptake of calcium by the sunflower tops as shown in Table 46 and Appendix Table 44. The average of the calcium percentage of the tops from the 0 level of aluminum was significantly different from the average of the tops grown in the presence of aluminum in the solution. The surprising aspect of the effect of aluminum was that the calcium content of the sunflower tops grown in the presence of aluminum in the solution was greater than the calcium content of the tops grown in the absence of aluminum. This was in direct contrast to the effect of aluminum and boron on the uptake of calcium by the sunflower tops in the first solution culture test, in which the presence of boron in the solution resulted in an increased uptake of calcium, but aluminum had no significant effect. The reason for this discrepancy was not clear, unless the difference in the size or age of the plants exerted an influence, the plants in the second solution culture test were much larger and were two weeks older at harvest than the plants in the first solution culture test.

There was a significant interaction effect between aluminum and boron on the uptake of calcium by the sunflower tops. This interaction meant that the sunflower tops with the highest percentage of calcium were from the jars containing the intermediate levels of aluminum and boron or the intermediate level of aluminum and no added boron. The lowest percentage of calcium was in the tops grown in the absence of both aluminum and boron applications. There was no significant difference among the calcium percentages of the tops grown in the other treatments.

TABLE 46.-Effect of aluminum and boron in nutrient solution culture on the uptake of calcium by sunflower tops in the second solution culture test

Aluminum added	Boron added, ppm.			Average
	0	0.5	1.0	
ppm.	%	%	%	%
0	0.83**	1.20	1.14	1.06
1	1.72	1.18	1.71	1.54
2	1.18	1.51	1.44	1.38
Average	1.24	1.30	1.43	1.32

**The standard error for these means is ± 0.13.

There were significant differences produced by an effect of aluminum, boron, and an interaction between aluminum and boron in the uptake of calcium by the sunflower roots, as shown in Table 47 and Appendix Table 45. There was a significant increase in the calcium uptake by the roots grown in the jars containing 0.5 ppm. and 1.0 ppm. of boron over the calcium uptake by the roots grown at the lowest level of boron. Aluminum applications caused a measurable decrease in the calcium uptake by the roots, in comparison to the uptake by the roots where boron was not added. The highest percentages of calcium were found in the roots grown in the jars receiving boron additions but not aluminum. Aluminum in the absence of boron decreased the uptake of calcium by the roots, but this effect was overcome to a large extent when boron was present in the solution.

The results of the second solution culture test again showed that boron exerted a great influence on the weights and the heights of the sunflower plants. In addition, boron influenced the uptake of aluminum by the vegetative parts of the sunflower plants, but aluminum in solu-

tion cultures actually did not increase the aluminum content of the sunflower tops.

TABLE 47.-Effect of aluminum and boron in nutrient solution culture on the uptake of calcium by sunflower roots in the second solution culture test

Aluminum added	Boron added, ppm.			Average
	0	0.5	1.0	
ppm.	%	%	%	%
0	.07**	.15	.12	.11
1	.08	.07	.09	.08
2	.08	.10	.09	.09
Average	.08	.11	.10	.09

**The standard error for the means is ± 0.01.

However, increased levels of aluminum in the solutions resulted in large increases in the accumulation of aluminum by the sunflower roots. This, again, was in agreement with the observation of McLean and Gilbert (44) that aluminum accumulated in the roots of plants. Aluminum in the solution cultures resulted in an increased uptake of calcium by sunflower tops, but there was a decrease in the uptake of calcium by the roots when aluminum was present. Boron in the solution cultures resulted in an increase in the uptake of calcium by the roots and showed a tendency to offset the adverse effect of aluminum to a large extent.

Third solution culture test

The pH values of the solution cultures used in this test were determined at the end of each week when the solutions were changed. It was quite apparent that the concentration of aluminum in the solution was very

influential in fixing the pH. The pH values of the solution cultures at the time the solutions were discarded are presented in Table 48. The increased pH of the solutions after the first solution change was probably caused by the increased growth of the plants.

TABLE 48.-The pH values[1] of the nutrient solution cultures used in the third solution culture test

PPM. of Al in solution	Dates on which solutions were changed				
	Original	March 14	March 21	March 28	April 4
	pH	pH	pH	pH	pH
0	5.9	5.8	5.7	6.0	6.5
2	5.7	5.6	5.6	5.6	6.0
4	5.4	5.3	5.5	5.6	6.0
6	5.3	5.8	5.2	5.6	5.8
8	5.0	5.6	5.1	5.7	5.8
10	4.7	5.6	5.1	5.6	5.7
12	4.5	5.4	5.0	5.5	5.6
14	5.7	5.5	4.9	5.5	5.5
16	5.4	5.5	4.7	5.4	5.4

[1]Average of four replications

The sunflower plants in this test responded almost immediately to the toxic effects of aluminum at the higher rates--from 6 ppm. to 16 ppm. of aluminum in solution. There was first a cessation of root growth, followed by the development of stubby root tips and a brownish discoloration of the roots. The leaves of the plants growing in the solutions containing from 10 ppm. to 16 ppm. of aluminum turned brown on the margins and the cotyledons on these plants soon died. The initial condition of shock lasted for over two weeks, after which time the roots of the affected plants began to grow to some extent.

The rates of aluminum in the nutrient solutions had a highly significant effect on the weights of the sunflower tops as shown in Table 48

of the Appendix. However, this difference was not significant until the rate of aluminum in solution reached 6 ppm. at which point there occurred a drop in the pH of the solution cultures. The differences among the weights of the tops of the plants grown in the solutions containing 0, 2, and 4 ppm. of added aluminum were not significant. However, these weights differed significantly from the weights of the tops produced by the other treatments. The regression of the weights of the sunflower tops on the levels of aluminum in the nutrient solutions was calculated to be very highly significant with a "t" value of 7.18 which was significant at the .001 per cent level of probability. This regression is expressed

$$\hat{Y} = 14.21 - 0.81X$$

where Y is the average weight of sunflower tops expected and X is the aluminum concentration in the nutrient solution. This regression effect is shown in Figure 1[4] and illustrates the inverse effect on the weights as the aluminum concentration is increased.

The weights of the sunflower roots are presented in Appendix Table 47. The root weights followed the same pattern as the top weights with respect to the response of weight to the levels of aluminum in solution. The regression of the weights of the sunflower roots on the rates of aluminum in solution was very highly significant with a "t" of 6.90 which was significant at the .001 level. The regression equation

$$\hat{Y} = 4.70 - 0.257X$$

as presented in Figure 2 shows that the weights of the roots decreased as

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[4]The "X" on the regression line indicates the origin for deviations, or the point where the average of ppm. of aluminum in solution and the average of the weights correspond.

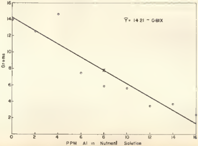

Figure 1.-Sunflower top weights in gram decrease as the concentration of aluminum in the nutrient solution is increased.

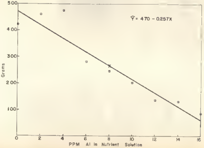

Figure 2.-Sunflower root weights in grams decrease as the concentration of aluminum in the nutrient solution is increased.

the concentration of aluminum in the nutrient solution increased.

There was a very highly significant difference in the heights of the sunflower plants, as shown in Appendix Table 48, due to rates of aluminum. As in the case of the plant weights, there was no significant difference among the heights of the plants grown in the solution cultures containing 0, 2, and 4 ppm. of added aluminum. The sharpest reductions in height occurred when the concentration of aluminum reached 6 ppm. and again when it reached 12 ppm. The "r" value of 0.10 for the regression of the plant heights on the concentration of aluminum in solution was very highly significant at the .001 level of probability. As presented in Figure 3, the regression equation

$$\hat{Y} = 25.26 - 0.74X$$

shows that the heights of the sunflower plants decreased as the concentration of aluminum in solution increased.

The boron contents of the sunflower tops and roots are shown in Table 49 and Table 50, respectively, of the Appendix. The levels of aluminum in solution had no significant effect on the uptake of boron by either the tops or the roots. It was obvious that aluminum accumulation in the roots did not set up a screen to prevent the entrance of boron.

The levels of aluminum in the solutions did not significantly influence the uptake of aluminum by the sunflower tops. However, there was a large increase in aluminum uptake by the sunflower plants grown in the solution cultures containing 14 and 16 ppm. of aluminum. The lack of a significant effect from aluminum in solution on the uptake of aluminum by the sunflower tops was in agreement with the results of the first and the second solution culture tests, where the aluminum levels were only 0.5,

1.0, and 2.0 ppm. in solution. The data on the uptake of aluminum by the sunflower tops are presented in Appendix Table 51.

The aluminum contents of the sunflower roots are presented in Table 52 of the Appendix. The results of this test were in agreement with the results of the first and second solution culture tests with respect to the accumulation of aluminum in the sunflower roots. There was a highly significant difference in the uptake of aluminum by the roots due to the levels of aluminum in the solution cultures. The uptake of aluminum varied from 130 ppm. in the roots from the lowest level of aluminum to 5100 ppm. in the roots from the highest level of aluminum. The smallest difference between any of the consecutive means occurred at the 2- and 4-ppm. of aluminum treatments where the difference was only 300 ppm. of aluminum. There was a significant decrease in the uptake of aluminum by the roots grown in the solution containing 14 ppm. of aluminum from the uptake by the roots grown in the solution containing 12 ppm. of aluminum. This decrease was probably caused by the high value of 11,100 ppm. of aluminum found in the first replication of the 12-ppm. of aluminum treatment and the low value of 4,600 ppm. of aluminum found in the third replication of the 14-ppm. of aluminum treatment. The regression of aluminum uptake by the roots on the levels of aluminum in the solution cultures was highly significant with a "t" value of 14.20 which was significant at the .001 level. The regression equation presented in Figure 4

$$\hat{Y} = 371X - 167$$

shows that the aluminum content of the sunflower roots increased as the rates of aluminum in the solution cultures increased.

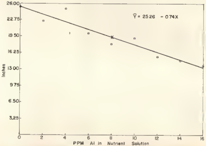

Figure 3.-Sunflower heights in inches decrease as the concentration of aluminum in the nutrient solution is increased.

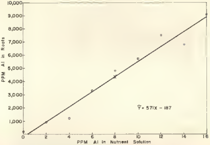

Figure 4.--Uptake of aluminum by sunflower roots increases as the concentration of aluminum in the nutrient solution is increased.

Aluminum additions to the nutrient solutions did not have a significant effect on the amounts of calcium found in the tops of the sunflower plants as shown in Appendix Table 33. However, there was a highly significant difference among treatments in the percentages of calcium found in the roots due to the levels of aluminum in the solutions. The calcium content varied from a low 0.28 per cent in the roots from the solution containing 16 ppm. of aluminum to a high of 0.74 per cent in the roots from the solution containing no added aluminum as shown in Table 54 of the Appendix. The regression of calcium in the roots on the levels of aluminum in the solution cultures was highly significant with a "t" value of 8.10 which was significant at the .001 level (Figure 5). The regression equation

$$\hat{Y} = 0.65 - 0.025X$$

shows that the calcium content of the roots decreased as the amount of aluminum in the solution increased.

It may be concluded from the results of the third solution culture test that aluminum in concentrations greater than 4 ppm. in the solution culture had a highly depressing effect on the heights and weights of the sunflower plants in this test. It was shown that increased rates of aluminum in the solution cultures had little effect on the uptake of boron by the sunflower plants. Increased rates of aluminum in the solution cultures resulted in greater accumulations of aluminum in the roots, but not in the tops of the sunflower plants. There was a sharp reduction in the uptake of calcium by the sunflower roots as the rates of aluminum in solution increased. However, there was little effect from aluminum in the uptake of calcium by the sunflower tops.

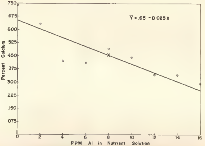

Figure 5.—Uptake of calcium by sunflower roots decreases as the concentration of aluminum in the nutrient solution is increased.

Boron-Aluminum Survey of Several Soil Series

The results of the boron, aluminum, and calcium analyses of the tomato leaves collected from different soil types in central and southern Florida are presented in Table 49. It was apparent that the aluminum content of tomato plants varied considerably among the soil types. The highest content of aluminum was in the tomato leaves collected from the Blanton fine sand on the Carlton farm and the lowest aluminum content was in the tomato lowest collected from the Leon fine sand having a heavy substratum on the Harllee farm. The boron content of the tomato leaves was not so variable as the aluminum content. It was interesting to note that the lowest uptake of boron was by the tomato plants grown on the Blanton fine sand on the Carlton farm where the highest uptake of aluminum occurred. The highest calcium content was, also, in the tomato leaves collected from the Carlton farm.

TABLE 49.-The boron, aluminum, and calcium contents[1] of the tomato leaves collected from different soil types in central and southern Florida

Location	Soil type	Boron	Aluminum	Calcium
		ppm.	ppm.	%
William Myshyk	Immokalee fine sand	64	119	.97
Dick Davis	Leon fine sand	51	91	.83
Carlton farm	Blanton fine sand	28	153	1.29
Harllee farm	Leon fine sand (heavy substratum)	61	21	1.22
Kleberry farm	Ruskin fine sand	65	24	.61

[1]Average of three determinations

The results of the boron, aluminum, and calcium analyses of the palmetto leaves collected in this experiment are presented in Table 50. The palmetto plants sampled were very low accumulators of the three ele-

cents for which the leaves were analyzed. Correlations among the boron, aluminum, and calcium contents of the tomato and the palmetto leaves were not significant.

TABLE 30.—The boron, aluminum, and calcium contents[1] of the palmetto leaves collected from different soil types in central and southern Florida

Location	Soil type	Boron	Aluminum	Calcium
		ppm.	ppm.	%
Williams Hyckyk	Immokalee fine sand	15	14	.04
Dick Davis	Leon fine sand	12	11	.03
Carlton farm	Blanton fine sand	11	16	.06
Harliee farm	Leon fine sand (heavy substratum)	13	11	.05
Elsberry farm	Ruskin fine sand	12	23	.05

[1]Average of three determinations

Although there was no significant correlation between the aluminum and the boron contents of the tomato leaves, there was a highly significant correlation, r = -.784, between the aluminum and the boron contents of the soils from which the leaves were collected. The regression of the hot-water soluble boron content on the aluminum content of the cultivated soils is shown in Figure 6. It may be seen from the regression line that the boron content of the soil decreased as the aluminum content increased.

The regression of the calcium content of the cultivated soils on the aluminum content of the cultivated soils is shown in Figure 7. The correlation coefficient, r = -.736, was highly significant. The regression line shows that the calcium content, as well as the boron content, of the cultivated soils decreased as the aluminum content increased. There was no significant correlation between the calcium content and the boron content of the cultivated soils.

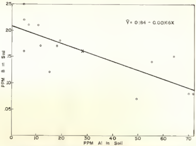

Figure 6.-The soil boron content decreases as the soil aluminum content increases in several soil types collected from cultivated areas in central and southern Florida.

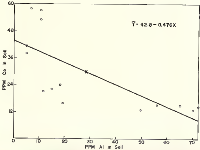

Figure 7.-The soil calcium content decreases as the soil aluminum content increases in several soil types collected from cultivated areas in central and southern Florida.

In Table 31 are presented the soil pH values and the boron, aluminum, and calcium contents of the cultivated soil samples collected from central and southern Florida. Attention is again directed to the Blanton fine sand from the Carlton farm which contained the lowest amount of boron and the highest amount of aluminum of the five soil types sampled. It should be recalled that the tomato leaves collected from this soil also contained a lower amount of boron and a higher amount of aluminum than the other tomato leaves.

TABLE 31.-The soil pH values and the boron, aluminum, and calcium contents[1] of the cultivated soils collected from central and southern Florida

Location	Soil type	Soil pH	Boron	Aluminum	Calcium
			ppm.	ppm.	ppm.
William Rychyk	Immokalee fine sand	5.67	.15	15	32
Dick Davis	Leon fine sand	4.91	.16	46	15
Carlton farm	Blanton fine sand	5.30	.66	64	15
Marlino farm	Leon fine sand (heavy substratum)	6.27	.31	5	40
Elaberry farm	Ruskin fine sand	6.76	.31	10	36

[1]Average of three determinations

The correlation between the calcium content and the aluminum content of the uncultivated soils was significant at the 5 per cent level with a correlation coefficient of -.555. The regression of the soil calcium content on the soil aluminum content is shown in Figure 8 and the regression line shows that the calcium content decreased as the aluminum content increased. There were no other significant correlations among the elements for which analyses were made in these soils.

The soil pH values and the boron, aluminum, and calcium contents of the uncultivated soils collected from central and southern Florida are presented in Table 32. It may be noticed that the Blanton fine sand from

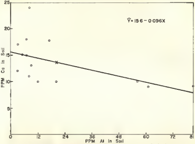

Figure 8.-The soil calcium content decreases as the soil aluminum content increases in several soil types collected from uncultivated areas in central and southern Florida.

the Carlton farm again contained the lowest boron and the highest aluminum content of the five soils analyzed.

TABLE 52.-The soil pH values and the boron, aluminum, and calcium contents[1] of the uncultivated soils collected from central and southern Florida

Location	Soil type	Soil pH	Boron	Aluminum	Calcium
			ppm.	ppm.	ppm.
William Nychyk	Immokalee fine sand	5.32	.09	13	16
Dick Davis	Leon fine sand	4.17	.16	6	13
Carlton farm	Blanton fine sand	5.48	.07	65	9
Merllee farm	Leon fine sand (heavy substratum)	5.39	.17	10	17
Elsberry farm	Ruskin fine sand	5.80	.35	5	19

[1]Average of three determinations

The results of this test did not reveal any significant correlation among the elements for which analyses were made in either the tomato leaves or the palmetto leaves. The lowest amounts of boron and the highest amounts of aluminum were found in the tomato leaves collected from the Blanton fine sand. In addition, the Blanton fine sand contained the lowest amount of boron and the highest amount of aluminum of the soils which were sampled.

In the cultivated soils highly significant correlations were found to exist between the boron and aluminum contents and between the calcium and aluminum contents. In both instances it was shown that the soil boron and the soil calcium contents decreased as the soil aluminum content increased. A significant correlation was found to exist between the calcium content and the aluminum content of the uncultivated soils.

SUMMARY AND CONCLUSIONS

An outdoor lysimeter test was conducted using 3- and 5-gallon glazed earthenware crocks buried in the soil and connected by drainage hose to leachate collectors consisting of 1-gallon glass jars. This test was designed to determine the effect of aluminum ion additions on the uptake of boron by plants and the possible interactions of aluminum and boron on the growth of plants. The effect of aluminum and boron on the uptake of calcium was also studied. Plant yields were recorded on an oven-dry weight basis. Boron, aluminum, and calcium analyses were made of all plant materials collected.

In this experiment one crop each of sunflowers, rutabagas, lettuce, and Louisiana S-1 white clover was grown. Plant nutrients, other than the boron and aluminum, were applied in sufficient quantities so that the plants were grown under conditions of high fertility. The sunflower plants showed no increase or decrease in yield from the addition of aluminum or boron salts to the soil. However, there was an increase in height due to the application of boron to the soil. The addition of boron resulted in an increased uptake of boron from the soil over the uptake from the check plots. There was also an increase in aluminum in the plants only at the highest rate of aluminum applied, 40 pounds of aluminum per acre. The calcium content of the sunflower plants was not affected by any treatment. There were no indications of an interaction effect of aluminum and boron on yields or on the uptake of aluminum, boron, or calcium.

The Blichton fine sand used in this test was very low in hot water-soluble boron and as a result the rutabaga plants showed severe signs of boron deficiency in the lysimeters containing no added boron. Although the top weights were not affected by the addition of boron to the soil, there were large increases in the root weights grown in the presence of added boron. Aluminum added to the soil had no effect on plant yields.

The uptake of boron by the rutabaga tops was increased in the presence of added boron. There was an interaction effect between the levels of boron and aluminum which resulted in an increase in boron uptake in the presence of 20 pounds per acre of applied aluminum and 1 pound of applied boron per acre. The uptake of boron by rutabaga roots was not significantly affected by the addition of either boron or aluminum to the soil. In contrast to boron, the uptake of aluminum by the rutabaga plants was not affected by aluminum or boron applications. However, there was an aluminum and boron interaction effect which resulted in a lower accumulation of aluminum in the leaves in the presence of boron applied to the soil in conjunction with applied aluminum. Calcium accumulated in the roots of the rutabagas in the absence of applied boron which suggested that boron was effective in the translocation of calcium.

Lettuce plants developed boron deficiency symptoms early in their growth in the lysimeters containing no added boron. However, there was no increase in yield from boron applied to the soil. Aluminum, on the other hand, caused a decrease in lettuce yields when applied at 20 and at 40 pounds per acre.

The application of boron to the soil resulted in no increase in the uptake of boron by lettuce. Aluminum applied at the rate of 40 pounds

per acre caused a sharp decrease in the uptake of boron as compared to the 0 and 20-pound per acre rates. The applied rates of aluminum were also effective in reducing the percentages of calcium found in the lettuce plants. Lettuce was found to be a relatively heavy accumulator of aluminum, but aluminum applied to the soil had little effect on the amounts of aluminum absorbed by the plants.

The Louisiana S-1 white clover displayed signs of boron deficiency in all of the lysimeters that had received no added boron. Both aluminum and boron influenced the yields of the clover with added aluminum causing a decrease in yield and added boron resulting in an increase in yield. The addition of boron to the soil increased the uptake of boron by the clover. However, the addition of aluminum to the soil did not increase the uptake of aluminum. Neither boron nor aluminum added to the soil had an effect on the uptake of calcium.

A greenhouse experiment was designed in order to determine the same points discussed above, but the growth medium used in this test was nutrient solution with boron and aluminum at specific levels. The sunflower plant was used for the indicator plant in this experiment.

The first and second tests in this experiment were almost alike except for the increased concentration of aluminum in the second test and the fact that the sunflower plants in the second test were allowed to grow approximately two weeks longer than the plants in the first test. The response to added boron by the root weights and by the top weights of the sunflower plants was highly significant in both tests. There was also a large increase in the height of the plants in both tests as a result of added boron. In the second test there was a decrease in height due to

added aluminum and there was no effect from the interaction of aluminum and boron. The reason for this difference between the first and second tests with respect to height was probably that the plants in the second test remained in contact with aluminum for a longer period of time.

The addition of boron to the nutrient solution resulted in increases in the uptake of boron by the sunflower tops in the first and in the second solution culture tests. However, the uptake of boron was much greater in the first test than in the second test. The amount of boron found in the roots was also much greater in the first than in the second test. There was no significant difference among the treatments in the uptake of boron by the roots in the first test, but there was a difference in the second test which resulted in a decrease in the uptake of boron by the roots grown in the presence of added boron. These findings suggested that the sunflower plants absorbed larger amounts of boron when they were younger, as in the first test, and that boron may have been immobilized in the roots in the absence of an adequate supply of boron.

The presence of added aluminum in the solution had no effect on the amount of aluminum found in the sunflower tops in either of the first two tests. In contrast, the presence of boron in the solution resulted in a decreased uptake of aluminum by the tops. The sunflower roots in both tests accumulated very large amounts of aluminum in comparison to the tops. In the first test the rates of applied aluminum had a highly significant effect on the amounts of aluminum found in the roots, but boron had little effect. However, in the second test the presence of added boron in the solution resulted in a decreased uptake of aluminum by the roots while the presence of aluminum in solution greatly increased the

amount of aluminum in the roots. There was also an interaction effect between aluminum and boron in the second solution culture test.

The absorption of calcium by the sunflower tops in the first and second solution culture tests followed the same trend as the absorption of boron in that there were greater calcium contents in the tops of the plants grown in the first test. The uptake of calcium by the tops was greater in the presence of added boron in the first test, but in the second test there was also an interaction effect between aluminum and boron in the nutrient solutions. The effect of aluminum and boron was the same on the uptake of calcium by the roots as on uptake of calcium by the tops in both tests, except there was an increase in uptake due to the presence of boron in the second test.

In the third solution culture test the rates of aluminum added to the solutions greatly influenced the yields, heights, uptake of aluminum by the roots, and the uptake of calcium by the roots. Linear regression equations showed that as the concentration of aluminum in solution increased there was a very highly significant decrease in the yields, heights, and calcium content of the roots, and a very highly significant increase in the aluminum content of the roots. There was no effect from aluminum on the uptake of boron by the tops or the roots, or on the uptake of calcium by the tops.

A survey of several soil types was conducted in central and south Florida. Tomato and palmetto leaf samples were collected in conjunction with samples of the soil in which the plants were growing. Analyses were made to determine the boron, aluminum, and calcium contents of the plant material and the soils in order to detect any correlations among the three

elements.

Five soil types were included in this study. The amount of hot water-soluble boron found in the soils ranged from a low of 0.06 ppm. in Blanton fine sand to a high of 0.35 ppm. in Ruskin fine sand. The amount of aluminum extracted by 2N ammonium acetate ranged from 65 ppm. in Blanton fine sand to 5 ppm. in Ruskin fine sand and Leon fine sand. The range in ammonium acetate extractable calcium was from 168 ppm. in the Ruskin fine sand to 28 ppm. in the Blanton fine sand. Significant associations were found to exist between the boron and aluminum contents of the cultivated soils and between the calcium and aluminum contents of the cultivated and the uncultivated soils. In each case, the amount of boron or calcium was found to decrease as the amount of aluminum in the soil increased.

The boron content of the tomato leaves was found to range between 28 and 65 ppm., the calcium content between 0.61 per cent and 1.29 per cent, and the aluminum content between 21 ppm. and 153 ppm. The palmetto leaves were found to contain very small amounts of each of the elements determined--11 to 15 ppm. of boron, 11 to 23 ppm. of aluminum, and 0.03 to 0.6 per cent of calcium. Correlations among the three elements were not significant in either plant species.

LITERATURE CITED

1. Addicott, F. T. Pollen germination and pollen tube growth, as influenced by pure growth substances. Plant Physiol. 18: 270-79. 1943.

2. Agulhon, H. The use of boron as a catalytic fertilizer. Compt. Rend. Acad. Sci. (Paris) 150: 288-91. 1910. Abst.: E. S. R. 23: 288.

3. ________. The Role of Boron in Plants. Thesis. Paris. 1910. Abst.: E. S. R. 23: 230.

4. Batjer, L. P. and Thompson, A. H. Effect of boric acid sprays applied during bloom upon the set of pear fruits. Proc. Amer. Soc. Hort. Sci. 53: 141-42. 1949.

5. Beckenbach, J. R. Functional relationships between boron and various anions in the nutrition of the tomato. Fla. Agr. Expt. Sta. Bull. 395. 1944.

6. Berger, K. C. and Truog, E. Boron determination in soils and plants. Indus. Eng. Chem., A. E. 11: 540. 1939.

7. Bertrand, G. and de Waal, H. L. Comparative boron content of plants grown on the same soil. Compt. Rend. Acad. Agr. 22: 324-31. 1936.

8. Blair, A. W. and Prince, A. L. Studies on the toxic properties of soils. Soil Sci. 15: 109-29. 1923.

9. Brenchley, W. E. Investigations on the effect of boron on plant life. Agr. Prog. (Agr. Ed. Assoc. London) 3: 104-5. 1926.

10. ________ and Warington, K. The role of boron in the growth of plants. Ann. Bot. 41: 167-87. 1927.

11. Chandler, F. B. Mineral nutrition of the genus _Brassica_ with particular reference to boron. Maine Agr. Expt. Sta. Bull. 404. 1941.

12. Chenery, E. M. A preliminary study of aluminum and the tea bush. Plant and Soil 6: 174-200. 1955.

13. Colwell, W. E. A biological method for determining the relative boron content of soils. Soil Sci. 56: 71-94. 1943.

14. ________. Intensified cropping to diagnose minor element deficiency, a method to determine the relative boron content of soils. Soil Sci. 62: 43-49. 1946.

15. ________ and Baker, G. O. Studies of boron deficiency in Idaho soils. Jour. Amer. Soc. Agron. 31: 503-12. 1939.

16. Cook, R. L. Borax as a control for heart rot of sugar beets. Better Crops with Plant Food 24 (5): 12-16, 39-46. 1940.

17. Davis, J. L. Effects of liming on response to minor elements of crimson clover, soybeans, and Alyce clover. Jour. Amer. Soc. Agron. 41: 368-74. 1949.

18. Duncan, D. B. Multiple range and multiple "F" tests. Biometrics 11: 1-42. 1955.

19. Eaton, F. M. Deficiency and toxicity of boron in plants. Jour. Agr. Res. 69: 237-77. 1944.

20. Eaton, S. V. Effects of boron deficiency and excess on plants. Plant Physiol. 15: 95-107. 1940.

21. Gauch, H. G. and Dugger, W. M., Jr. The role of boron in the translocation of sucrose. Plant Physiol. 28: 457-67. 1953.

22. Gilbert, B. E. and Pember, F. R. Further evidence concerning the toxic action of aluminum in connection with plant growth. Soil Sci. 31: 267-73. 1931.

23. ________ and ________. Tolerance of certain weeds and grasses to toxic aluminum. Soil Sci. 39: 425-29. 1935.

24. Grizzard, A. L. and Matthews, E. M. The effect of boron on seed production of alfalfa. Jour. Amer. Soc. Agron. 34: 365-68. 1942.

25. Haas, A. R. C. Growth stimulation in Valencia orange trees on sour orange rootstock by means of aluminum citrate. Calif. Citrograph 32: 198-99. 1947.

26. ________ and Klotz, L. J. Some anatomical and physiological changes in citrus produced by boron deficiency. Hilgardia 5: 175-96. 1931.

27. ________ and ________. Further evidence on the necessity of boron for health in citrus. Bot. Gaz. 92: 94-100. 1931.

28. Harris, G. H. Some effect of microelements on growth and storage of carrots and turnips. Proc. Amer. Soc. Hort. Sci. 43: 219-24. 1943.

29. Hartwell, B. L. and Pember, F. R. The presence of aluminum as a reason for the difference in the effect of so-called acid soil on barley and rye. Soil Sci. 6: 259-77. 1918.

30. Henderson, J. H. M. and Veal, M. P. The effect of the interrelationship of boron and manganese on the growth and calcium uptake of blue lupine (Lupinus angustifolius L.) in solution culture. Plant Physiol. 23: 609-20. 1948.

31. Hoagland, D. R. and Arnon, D. I. The water-culture method for growing plants without soil. Calif. Expt. Sta. Cir. 347. 1950.

32. Hutchinson, G. E. Aluminum in soil, plants, and animals. Soil Sci. 60: 29-40. 1945.

33. Jacob, W. C. and White-Stevens, R. H. Studies in the minor element nutrition of vegetable crop plants. II. The interrelation of potash, boron, and manganese upon the flavor and sugar content of melons. Proc. Amer. Soc. Hort. Sci. 39: 369-73. 1941.

34. Jones, H. E. and Scarseth, G. D. The calcium-boron balance in plants as related to boron needs. Soil Sci. 57: 15-23. 1944.

35. Latimer, W. M. and Hildebrand, J. H. Reference Book of Inorganic Chemistry. Revised ed. The Macmillan Co., New York, N.Y. 1944.

36. Leaf, G. L. Boron in relation to water balance in plants. Proc. Iowa Acad. Sci. 60: 176-81. 1953.

37. Liebig, G. F.,Jr., Vanselow, A. P., and Chapman, H. D. Effects of aluminum on copper toxicity as revealed by solution culture and spectrographic studies of citrus. Soil Sci. 38: 341-57. 1942.

38. Lipman, C. B. Importance of silicon, aluminum, and chlorine for higher plants. Soil Sci. 45: 189-98. 1938.

39. Low, P. F. The role of aluminum in the titration of bentonite. Soil Sci. Soc. Proc. 19: 135-39. 1955.

40. Lowenkampt, H. Nutrient effects of boron on growth and development of the sunflower. Bot. Gaz. 104: 316-22. 1942.

41. MacDougall, D. and Biggs, D. A. Estimation of boron in plant tissue, by modified quinalizarin method. Anal. Chem. 34: 566-69. 1952.

42. McLean, E. O., Heddleson, M. R., Bartlett, R. J., and Holowaychuk, N. Aluminum in soils: I. Extraction methods and magnitudes in clays and Ohio soils. Soil Sci. Soc. Proc. 22: 382-87. 1958.

43. McLean, F. T. and Gilbert, B. E. The relative aluminum tolerance of crop plants. Soil Sci. 34: 122-34. 1927.

44. ________ and ________. Aluminum toxicity. Plant Physiol. 3: 293-302. 1928.

45. Mellor, J. W. A Comprehensive Treatise on Inorganic and Theoretical Chemistry. Vol. V. Longmans, Green and Co., London. 1924.

46. Minarik, C. E. and Shive, J. W. The effect of boron in the substrate on calcium accumulation by soybean plants. Amer. Jour. Bot. 26: 827-31. 1939.

47. Mitchell, J. W., Benedict, H. M., and Whiting, A. G. Growth, rubber storage, and seed production by guayule as affected by boron supply. Bot. Gaz. 106: 148-57. 1944.

48. Mohr, C. E. Plant symptoms of boron deficiency and the effects of borax on the yield and chemical composition of several crops. Soil Sci. 56: 55-65. 1948.

49. Page, N. R. and Paden, W. R. Boron supplying power of several South Carolina soils. Soil Sci. 77: 427-34. 1954.

50. Peligot, E. Concerning the action that boric acid and borates exercise on vegetables. Compt. Rend. (Paris) 83: 686-88. 1876. Abst.: Minor Element Bibl. 1: 242 (4). 1948.

51. Piland, J. R. and Ireland, C. F. Application of borax produces seed set in alfalfa. Jour. Amer. Soc. Agron. 33: 938-39. 1941.

52. ________, Ireland, C. F., and Reisenauer, H. M. The importance of borax in legume seed production in the South. Soil Sci. 57: 75-84. 1944.

53. Reeve, E. and Shive, J. W. K-B and Ca-B relationships in plant nutrition. Soil Sci. 57: 1-14. 1944.

54. Robinson, W. O. and Edgington, G. Minor elements in plants and some accumulator plants. Soil Sci. 60: 15-28. 1945.

55. Schmehl, W. R., Peech, M., and Bradford, R. Influence of soil acidity on absorption of calcium by alfalfa as revealed by radiocalcium. Soil Sci. 73: 11-21. 1952.

56. Scofield, C. S., Wilcox, L. V., and Blair, G. Y. Boron absorption by sunflower seedlings. Jour. Agr. Res. 61: 41-56. 1940.

57. Shive, J. W. The adequacy of the boron and manganese content of natural nitrate of soda to support plant growth in sand culture. N. J. Expt. Sta. Bull. 603. 1936.

58. Shuster, C. E. and Stephenson, R. E. Sunflower as an indicator of boron deficiency in soils. Jour. Amer. Soc. Agron. 32: 607-21. 1940.

59. Snedecor, G. W. Statistical Methods. Fifth ed. The Iowa State College Press, Ames, Iowa. 1956.

60. Sommer, A. L. Studies concerning the essential nature of aluminum and silicon for plant growth. Calif. Univ. Pubs. Agr. Sci. 5 (2): 57-81. 1926.

61. Stephenson, R. E. and Shuster, C. E. Laboratory, greenhouse, and field methods of studying fertilizer needs of orchard soils. Soil Sci. 52: 137-53. 1941.

62. Wadleigh, C. H. and Shive, J. B. A microchemical study of the effects of boron deficiency in cotton seedlings. Soil Sci. 47: 33-36. 1939.

63. Warington, K. The effect of boric acid and borax on the broad bean and certain other plants. Ann. Bot. 37: 629-72. 1923.

64. ________. Studies in the absorption of calcium from nutrient solutions with special reference to the presence or absence of boron. Ann. Bot. 48: 743-76. 1934.

65. Wear, J. I. Boron requirements of crops in Alabama. Ala. Agr. Sta. Bull. 305. 1957.

66. White-Stevens, R. H. Carbohydrate metabolism in relation to boron nutrition. Proc. Amer. Soc. Hort. Sci. 36: 537-43. 1938.

67. Wright, K. E. Internal precipitation of phosphorus in relation to aluminum toxicity. Plant Physiol. 18: 708-12. 1943.

68. ________ and Donahue, B. A. Aluminum toxicity studies with radioactive phosphorus. Plant Physiol. 28: 674-80. 1953.

69. Yuan, T. L. and Fiskell, J. G. A. Aluminon studies. Soil and plant analysis by modification of the aluminon method. Agr. and Food Chem. 7: 115-17. 1959.

APPENDIX

TABLE 1.-The original pH values of Blanton fine sand used in the first lysimeter test

Treatment		Replicates				Average
Al	B	1	2	3	4	
lb./acre	lb./acre	pH	pH	pH	pH	pH
0	0	6.00	6.00	5.95	5.80	5.94
0	0.5	6.30	5.95	6.25	5.80	6.00
0	1.0	6.80	6.20	5.80	6.10	6.15
0	2.0	6.20	6.80	6.05	6.20	6.21
10	0	6.20	6.20	6.30	5.80	6.12
10	0.5	6.30	5.80	5.80	6.00	5.97
10	1.0	6.00	6.03	5.80	5.80	5.91
10	2.0	6.10	6.20	6.30	5.80	6.00
20	0	5.80	6.80	6.20	6.05	6.09
20	0.5	6.15	6.43	6.30	5.80	6.20
20	1.0	6.55	6.20	6.80	5.80	6.19
20	2.0	6.80	6.80	6.80	5.80	6.12
40	0	6.43	6.20	6.00	5.95	6.15
40	0.5	6.25	6.33	5.95	5.85	6.17
40	1.0	6.20	6.30	6.50	6.00	6.27
40	2.0	6.15	6.00	5.95	5.80	5.97

Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F" value
Total	63	2.9425		
Treatment	15	.7031	.0469	1.31
Blocks	1	.5532	.5532	15.41**
Error	47	1.6862	.0359	

**Significant at the .01 level

TABLE 2.-The original boron content of Blanton fine sand used in the first lysimeter test

Treatment		Replicates				Average
Al	B	1	2	3	4	
lb./acre	lb./acre	ppm.	ppm.	ppm.	ppm.	ppm.
0	0	.08	.05	.08	.06	.07
0	0.5	.07	.08	.08	.06	.07
0	1.0	.08	.11	.06	.08	.08
0	2.0	.07	.08	.08	.08	.08
10	0	.06	.07	.06	.10	.07
10	0.5	.08	.10	.06	.08	.08
10	1.0	.07	.06	.10	.08	.08
10	2.0	.09	.07	.10	.07	.08
20	0	.10	.08	.11	.07	.08
20	0.5	.06	.08	.05	.12	.08
20	1.0	.10	.12	.08	.08	.09
20	2.0	.08	.08	.07	.06	.08
40	0	.08	.08	.05	.06	.08
40	0.5	.10	.07	.12	.06	.08
40	1.0	.08	.05	.07	.10	.07
40	2.0	.08	.08	.05	.07	.07

Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F" value
Total	63	.0206		
Treatment	15	.0040	.00027	
Blocks	1	.0010	.00010	
Error	47	.0165	.00035	

TABLE 3.-Effect of aluminum and boron applied to Blanton fine sand on the weights[1] of sunflowers in the first lysimeter test

Treatment		Replicates				Average
Al	B	1	2	3	4	
lb./acre	lb./acre	g.	g.	g.	g.	g.
0	0	20	18	13	14	16.2
0	0.5	23	32	14	13	20.5
0	1.0	19	13	17	12	15.2
0	2.0	24	23	13	13	18.2
10	0	18	13	11	11	13.2
10	0.5	23	27	14	13	19.2
10	1.0	13	26	13	13	16.2
10	2.0	15	25	15	13	17.0
20	0	18	18	16	13	16.2
20	0.5	14	18	10	13	13.7
20	1.0	13	13	12	17	13.7
20	2.0	18	29	18	13	19.5
40	0	16	15	15	7	13.2
40	0.5	15	11	10	13	12.2
40	1.0	19	15	11	14	14.7
40	2.0	19	21	13	14	16.7

[1]Oven-dry weights

Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F" value
Total	63	1,514		
Blocks	3	529	529.00	38.90**
Treatment	15	346	23.07	1.70
Rates of Al	3	95	31.67	2.33
Rates of B	3	92	30.67	2.26
Al x B	9	159	17.67	1.30
Error	47	639	13.60	

**Significant at the .01 level

TABLE 4.-Effect of aluminum and boron applied to Blanton fine sand on the heights of sunflowers in the first lysimeter test

Treatment		Replicates				Average
Al	θ	1	2	3	4	
lb./acre	lb./acre	in.	in.	in.	in.	in.
0	0	34.5	36.5	33.0	29.5	33.4
0	0.5	35.0	46.5	36.5	34.0	36.0
0	1.0	33.0	28.5	36.0	30.5	32.0
0	2.0	40.5	36.0	31.0	35.0	35.6
10	0	30.0	33.0	32.0	28.5	30.9
10	0.5	44.5	42.0	34.5	36.5	39.4
10	1.0	30.0	36.5	36.0	32.0	33.9
10	2.0	36.0	36.5	34.5	27.5	34.1
20	0	26.5	24.0	36.0	35.5	31.0
20	0.5	48.5	42.5	29.0	33.0	37.7
20	1.0	35.5	39.0	31.0	40.0	36.4
20	2.0	34.0	44.0	41.5	34.0	36.4
40	0	34.0	31.0	28.0	24.0	29.2
40	0.5	36.0	26.0	35.0	31.0	32.5
40	1.0	36.5	36.0	28.5	33.0	34.0
40	2.0	37.0	36.0	31.0	36.0	33.5

Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F" value
Total	63	1,678		
Blocks	1	166	166.00	7.94**
Treatment	15	529	35.27	1.69
Rates of Al	3	107	35.67	1.71
Rates of θ	3	290	96.67	4.62**
Al x θ	9	132	14.67	
Error	47	983	20.91	

**Significant at the .01 level

TABLE 5.—Effect of aluminum and boron applied to Blanton fine sand on the uptake of boron by sunflowers in the first lysimeter test

Treatment		Replicates				Average
Al	B	1	2	3	4	
lbs./acre	lbs./acre	ppm.	ppm.	ppm.	ppm.	ppm.
0	0	59	59	66	66	67
0	0.5	82	65	97	97	85
0	1.0	109	106	75	103	98
0	2.0	109	113	136	118	119
10	0	47	63	72	82	66
10	0.5	74	66	69	113	80
10	1.0	112	91	115	92	102
10	2.0	129	100	109	120	114
20	0	77	53	47	75	63
20	0.5	64	75	113	87	85
20	1.0	137	127	92	88	106
20	2.0	129	127	63	65	96
40	0	90	67	73	132	92
40	0.5	94	92	85	101	93
40	1.0	117	101	120	88	106
40	2.0	106	127	101	113	112

Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F" value
Total	63	34,626		
Blocks	1	42	42	
Treatment	15	18,149	1,209	3.45
Rates of Al	3	1,454	485	1.39
Rates of B	3	14,532	4,844	13.84**
Al x B	9	2,163	240	
Error	47	16,435	350	

**Significant at the .01 level

TABLE 6.-Effect of aluminum and boron applied to Blanton fine sand on the uptake of aluminum by sunflowers in the first lysimeter test

Treatment		Replicates				Average
Al	B	1	2	3	4	
lb./acre	lb./acre	ppm.	ppm.	ppm.	ppm.	ppm.
0	0	70	80	52	46	62
0	0.5	84	74	42	82	70
0	1.0	72	128	50	74	81
0	2.0	80	82	108	60	82
10	0	106	98	78	62	86
10	0.5	48	50	62	74	58
10	1.0	152	138	54	62	101
10	2.0	110	62	48	96	78
20	0	95	46	46	44	58
20	0.5	60	66	90	44	70
20	1.0	58	70	30	108	66
20	2.0	145	66	89	82	95
40	0	132	152	66	145	124
40	0.5	100	136	85	100	132
40	1.0	174	110	44	34	90
40	2.0	70	126	66	84	66

Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F" value
Total	63	79,810		
Blocks	1	8,859	8,859	9.50**
Treatment	15	27,137	1,809	1.94
Rates of Al	3	12,905	4,302	4.62**
Rates of B	3	153	51	
Al x B	9	14,079	1,564	1.68
Error	47	43,814	932	

**Significant at the .01 level

TABLE 7.—Effect of aluminum and boron applied to Blanton fine sand on the uptake of calcium by sunflowers in the first lysimeter test

Treatment		Replicates				Average
Al	B	1	2	3	4	
lb./acre	lb./acre	%	%	%	%	%
0	0	.30	.46	.54	.41	.43
0	0.5	.41	.33	.51	.51	.44
0	1.0	.41	.40	.46	.53	.45
0	2.0	.44	.43	.50	.44	.45
10	0	.35	.43	.39	.53	.42
10	0.5	.41	.38	.50	.58	.47
10	1.0	.41	.36	.45	.48	.42
10	2.0	.39	.49	.51	.51	.47
20	0	.34	.49	.45	.45	.43
20	0.5	.59	.43	.51	.48	.50
20	1.0	.24	.34	.41	.54	.38
20	2.0	.35	.37	.44	.41	.39
40	0	.39	.43	.41	.42	.41
40	0.5	.45	.45	.37	.46	.43
40	1.0	.42	.41	.46	.50	.46
40	2.0	.30	.39	.41	.56	.41

Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F" value
Total	63	.3072		
Blocks	1	.0871	.0871	24.19**
Treatment	15	.0520	.0003	
Rates of Al	3	.0059	.0002	
Rates of B	3	.0126	.0042	1.17
Al x B	9	.0335	.0037	1.03
Error	47	.1681	.0036	

**Significant at the .01 level

TABLE 8.--Effect of aluminum and boron applied to Blanton fine sand on the total amounts of boron leached from lysimeters in the first lysimeter test

Treatment		Replicates				Average
Al	B	1	2	3	4	
lb./acre	lb./acre	mg.	mg.	mg.	mg.	mg.
0	0	0	0	0.83	0.67	0.37
0	0.5	2.21	1.89	1.52	0.82	1.61
0	1.0	2.74	2.75	1.88	2.35	2.43
0	2.0	3.86	4.22	2.22	2.71	3.25
10	0	0.58	0.91	0.26	0.44	0.55
10	0.5	0.55	0.21	1.32	0.92	0.75
10	1.0	1.10	2.96	2.38	3.17	2.40
10	2.0	4.58	2.74	2.33	2.36	3.00
20	0	0.35	0.33	0.65	0.64	0.49
20	0.5	1.33	2.67	0.99	0.93	1.44
20	1.0	3.12	2.53	2.44	2.40	2.62
20	2.0	2.33	3.62	0.46	0.53	1.73
40	0	0.35	0.53	0.38	0.45	0.43
40	0.5	1.33	1.44	1.30	0.75	1.20
40	1.0	2.23	1.73	1.57	2.02	1.89
40	2.0	3.34	4.61	1.91	2.40	3.06

Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F" value
Total	63	85.5526		
Blocks	1	4.5156	4.5156	10.62**
Treatment	15	61.0619	4.0708	9.58**
Rates of Al	3	1.0627	.3542	
Rates of B	3	52.3496	17.4499	41.06**
Al x B	9	7.6496	.8500	2.00
Error	47	19.9751	.4250	

**Significant at the .01 level

TABLE 9.-Effect of aluminum and boron applied to Blichton fine sand on the weights[1] of rutabaga tops in the second lysimeter test

Treatment		Replicates			Average
Al	B	1	2	3	
lb./acre	lb./acre	g.	g.	g.	g.
0	0	7.5	10.0	5.5	7.7
0	1	10.5	10.5	5.5	8.8
0	2	12.0	9.5	10.5	10.7
20	0	11.5	4.5	5.5	7.2
20	1	11.5	8.5	11.0	10.3
20	2	9.5	8.5	11.5	9.8
40	0	10.5	7.0	8.0	8.5
40	1	10.5	7.5	10.0	9.3
40	2	6.0	5.0	8.5	6.5

[1]Oven-dry weights

Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F" value
Total	26	136.19		
Treatment	8	49.52	6.19	1.29
Rates of Al	2	5.69	2.84	
Rates of B	2	14.13	7.06	1.47
Al x B	4	29.70	7.42	1.54
Error	18	86.67	4.81	

TABLE 10.—Effect of aluminum and boron applied to Blichton fine sand on the weights[1] of rutabaga roots in the second lysimeter test

Treatment		Replicates			Average
Al	B	1	2	3	
lb./acre	lb./acre	g.	g.	g.	g.
0	0	5.0	7.0	5.0	5.7
0	1	18.5	12.0	6.0	12.2
0	2	18.0	14.5	14.5	15.7
20	0	9.5	3.0	6.5	6.3
20	1	20.0	10.0	13.5	14.5
20	2	17.5	11.0	14.5	14.3
40	0	7.5	6.0	6.0	6.5
40	1	14.5	7.5	9.0	10.3
40	2	9.5	3.0	13.0	8.5

[1]Oven-dry weights

Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F" value
Total	26	625.67		
Treatment	8	362.67	45.33	3.10*
Rates of Al	2	55.39	27.69	1.90
Rates of B	2	248.17	124.08	8.49**
Al x B	4	59.11	14.78	1.01
Error	18	263.00	14.61	

*Significant at the .05 level
**Significant at the .01 level

TABLE 11.–Effect of aluminum and boron applied to Blichton fine sand on the uptake of boron by rutabaga tops in the second lysimeter test

Treatment		Replicates			Average
Al	B	1	2	3	
lb./acre	lb./acre	ppm.	ppm.	ppm.	ppm.
0	0	32	33	42	36
0	1	59	59	52	57
0	2	83	95	69	82
20	0	28	27	29	28
20	1	72	67	98	79
20	2	73	79	85	79
40	0	33	33	33	33
40	1	59	63	58	60
40	2	85	80	70	78

Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F" value
Total	26	12,908		
Treatment	8	11,718	1,465	22.20**
Rates of Al	2	118	59	
Rates of B	2	10,729	5,364	81.77**
Al x B	4	871	218	3.30*
Error	18	1,190	61	

*Significant at the .05 level
**Significant at the .01 level

TABLE 12.-Effect of aluminum and boron applied to Blichton fine sand on the uptake of boron by rutabaga roots in the second lysimeter test

Treatment		Replicates			Average
Al	B	1	2	3	
lb./acre	lb./acre	ppm.	ppm.	ppm.	ppm.
0	0	27	37	75	53
0	1	47	47	63	53
0	2	40	47	60	49
20	0	50	32	42	41
20	1	63	47	57	56
20	2	60	55	125	80
40	0	55	52	32	40
40	1	80	62	47	63
40	2	60	92	62	71

Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F" value
Total	26	10,114		
Treatment	8	3,705	463	1.30
Rates of Al	2	427	213	
Rates of B	2	1,781	890	2.50
Al x B	4	1,497	374	1.05
Error	18	350	350	

TABLE 13.—Effect of aluminum and boron applied to Blichton fine sand on the uptake of aluminum by rutabaga tops in the second lysimeter test

Treatment		Replicates			Average
Al	B	1	2	3	
lb./acre	lb./acre	ppm.	ppm.	ppm.	ppm.
0	0	300	160	260	240
0	1	160	165	280	202
0	2	135	170	115	140
20	0	135	390	370	298
20	1	155	200	240	198
20	2	215	250	210	225
40	0	220	285	320	275
40	1	125	350	200	158
40	2	280	470	400	383

Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F" value
Total	26	227,767		
Treatment	8	135,283	16,910	3.29*
Rates of Al	2	27,950	13,975	2.72
Rates of B	2	35,117	17,558	3.42
Al x B	4	72,216	18,054	3.51*
Error	18	92,484	5,138	

*Significant at the .05 level

TABLE 14.-Effect of aluminum and boron applied to Blichton fine sand on the uptake of aluminum by rutabaga roots in the second lysimeter test

Treatment		Replicates			Average
Al	B	1	2	3	
lb./acre	lb./acre	ppm.	ppm.	ppm.	ppm.
0	0	950	800	610	785
0	1	1050	520	790	705
0	2	800	850	518	735
20	0	390	430	600	475
20	1	1080	670	960	905
20	2	830	500	840	725
40	0	910	1650	720	1095
40	1	960	950	640	850
40	2	670	960	510	715

Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F" value
Total	26	1,785,300		
Treatment	8	666,200	83,300	1.34
Rates of Al	2	158,300	79,100	1.27
Rates of B	2	68,400	34,200	
Al x B	4	439,500	109,900	1.77
Error	18	1,110,100	62,200	

TABLE 15.-Effect of aluminum and boron applied to Blichton fine sand on the uptake of calcium by rutabaga tops in the second lysimeter test

Treatment		Replication			Average
Al	B	1	2	3	
lb./acre	lb./acre	o/o	o/o	o/o	o/o
0	0	.31	.33	.28	.31
0	1	.35	.35	.33	.33
0	2	.40	.35	.39	.38
20	0	.31	.35	.29	.32
20	1	.35	.28	.31	.31
20	2	.33	.33	.33	.33
40	0	.31	.40	.35	.35
40	1	.31	.42	.37	.37
40	2	.40	.33	.31	.35

Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F" value
Total	26	.0361		
Treatment	8	.0148	.0018	1.00
Rates of Al	2	.0065	.0032	1.78
Rates of B	2	.0023	.0011	
Al x B	4	.0060	.0015	
Error	18	.0213	.0018	

TABLE 16.-Effect of aluminum and boron applied to Blichton fine sand on the uptake of calcium by rutabaga roots in the second lysimeter test

Treatment		Replicates			Average
Al	B	1	2	3	
lb./acre	lb./acre	%	%	%	%
0	0	.40	.53	.53	.49
0	1	.20	.26	.53	.33
0	2	.20	.20	.20	.20
20	0	.60	.76	.23	.53
20	1	.23	.26	.20	.23
20	2	.23	.23	.53	.33
40	0	.43	.46	.46	.45
40	1	.40	.40	.26	.35
40	2	.26	.53	.40	.40

Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F" value
Total	26	.6275		
Treatment	8	.2947	.0368	1.99
Rates of Al	2	.0170	.0085	
Rates of B	2	.1993	.0996	5.38**
Al x B	4	.0784	.0196	1.06
Error	18	.3328	.0185	

**Significant at the .01 level

TABLE 17.--Effect of aluminum and boron applied to Blichton fine sand on the total amounts of boron leached from lysimeters containing rutabagas in the second lysimeter test

Treatment		Replicates			Average
Al	B	1	2	3	
lb./acre	lb./acre	mg.	mg.	mg.	mg.
0	0	1.09	0.83	0.62	0.85
0	1	1.71	3.07	0.29	1.69
0	2	2.35	1.15	3.56	2.35
20	0	0.95	1.41	0.81	1.06
20	1	1.49	0.42	1.66	1.19
20	2	2.98	2.98	2.49	2.82
40	0	1.06	1.15	1.59	1.27
40	1	1.44	1.48	1.53	1.48
40	2	3.39	2.95	2.86	3.07

Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F" value
Total	26	23.9507		
Treatment	8	15.4883	1.9360	4.12**
Rates of Al	2	.4891	.2445	
Rates of B	2	14.0525	7.0262	14.95**
Al x B	4	.9467	.2367	
Error	18	8.4624	.4701	

**Significant at the .01 level

TABLE 18.—Effect of aluminum and boron applied to Klickton fine sand on the weights[1] of lettuce plants in the second lysimeter test

Treatment		Replicates			Average
Al	B	1	2	3	
lb./acre	lb./acre	g.	g.	g.	g.
0	0	5.3	4.1	4.9	4.8
0	1	4.6	6.3	3.2	4.7
0	2	4.9	5.7	6.2	5.6
20	2	4.8	5.9	7.2	6.0
20	1	3.2	5.9	3.4	4.2
20	2	4.8	3.6	3.6	4.0
40	0	1.9	1.5	2.9	2.1
40	1	4.2	5.1	2.6	4.0
40	2	4.4	5.4	3.8	4.5

[1]Oven-dry weights

Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F" value
Total	26	49.83		
Treatment	8	29.48	3.68	3.26*
Rates of Al	2	11.10	5.55	4.91*
Rates of B	2	1.13	.56	
Al x B	4	17.25	4.31	3.81*
Error	18	20.35	1.13	

*Significant at the .05 level

TABLE 19.—Effect of aluminum and boron applied to Blichton fine sand on the uptake of boron by lettuce plants in the second lysimeter test

Treatment		Replicates			Average
Al	B	1	2	3	
lb./acre	lb./acre	ppm.	ppm.	ppm.	ppm.
0	0	13	20	21	18
0	1	50	54	47	50
0	2	45	71	76	64
20	0	27	24	29	27
20	1	56	45	45	49
20	2	83	53	45	60
40	0	31	27	22	27
40	1	71	69	76	72
40	2	84	85	71	80

Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F" value
Total	26	13,103		
Treatment	8	11,402	1,425	15.16**
Rates of Al	2	1,336	668	7.11**
Rates of B	2	9,578	4,789	50.95**
Al x B	4	488	122	1.30
Error	18	1,701	94	

**Significant at the .01 level

TABLE 20.-Effect of aluminum and boron applied to Olichton fine sand on the uptake of aluminum by lettuce plants in the second lysimeter test

Treatment		Replicates			Average
Al	B	1	2	3	
lb./acre	lb./acre	ppm.	ppm.	ppm.	ppm.
0	0	440	440	340	410
0	1	470	400	560	480
0	2	490	460	480	480
20	0	450	490	480	470
20	1	430	660	460	520
20	2	350	420	560	440
40	0	550	540	440	510
40	1	460	470	450	460
40	2	460	470	540	500

Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F" value
Total	26	120,275		
Treatment	8	28,408	2,551	
Rates of Al	2	4,475	2,237	
Rates of B	2	2,452	1,226	
Al x B	4	21,481	5,270	1.03
Error	18	91,867	5,104	

TABLE 21.—Effect of aluminum and boron applied to Blichton fine sand on the uptake of calcium by lettuce plants in the second lysimeter test

Treatment		Replicates			Average
Al	B	1	2	3	
lb./acre	lb./acre	%	%	%	%
0	0	.16	.14	.14	.15
0	1	.17	.14	.15	.15
0	2	.14	.14	.15	.14
20	0	.12	.12	.14	.13
20	1	.14	.11	.15	.13
20	2	.14	.12	.12	.13
40	0	.12	.08	.14	.12
40	1	.12	.11	.11	.12
40	2	.12	.12	.11	.12

Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F" value
Total	26	.0091		
Treatment	8	.0048	.00060	2.50*
Rates of Al	2	.0045	.00225	9.20**
Rates of B	2	.0002	.00010	
Al x B	4	.0001		
Error	18	.0043	.00024	

*Significant at the .05 level
**Significant at the .01 level

TABLE 22.-Effect of aluminum and boron applied to Blichton fine sand on the total amounts of boron leached from lysimeters containing lettuce in the second lysimeter test

Treatment		Replicates			Average
Al	B	1	2	3	
lb./acre	lb./acre	mg.	mg.	mg.	mg.
0	0	0.27	0.82	0.54	0.54
0	1	2.67	1.86	1.22	1.92
0	2	4.93	3.20	2.78	3.64
20	0	0.51	1.00	0.78	0.78
20	1	1.56	1.47	2.69	1.91
20	2	2.38	3.56	4.93	3.62
40	0	1.21	0.81	1.22	1.08
40	1	1.19	2.08	2.00	1.76
40	2	1.87	1.22	4.28	2.46

Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F" value
Total	26	44.1505		
Treatment	8	30.2513	3.7814	4.90**
Rates of Al	2	.5614	.2807	
Rates of B	2	27.1027	13.5063	17.49**
Al x B	4	2.6772	.6693	
Error	18	13.8992	.7722	

**Significant at the .01 level

TABLE 23.-Effect of aluminum and boron applied to Leighton fine sand on the weights[1] of white clover in the second lysimeter test

Treatment		Replicates			Average
Al	B	1	2	3	
lb./acre	lb./acre	g.	g.	g.	g.
0	0	20.5	21.5	22.0	21.3
0	1	27.0	24.5	23.0	24.8
0	2	28.0	22.0	24.0	24.7
20	0	18.5	15.5	15.0	16.3
20	1	23.0	21.0	21.0	21.7
20	2	18.5	24.0	22.0	21.5
40	0	17.5	18.5	23.5	19.8
40	1	25.0	24.0	17.0	22.0
40	2	19.0	19.0	19.0	17.0

[1]Oven-dry weights

Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F" value
Total	26	343.24		
Treatment	8	207.24	25.90	3.43*
Rates of Al	2	90.96	45.48	6.02**
Rates of B	2	60.51	30.25	4.00*
Al x B	4	55.77	13.94	1.84
Error	18	136.00	7.56	

*Significant at the .05 level
**Significant at the .01 level

TABLE 24.-Effect of aluminum and boron applied to Blichton fine sand on the uptake of boron by white clover in the second lysimeter test

Treatment		Replicates			Average
Al	B	1	2	3	
lb./acre	lb./acre	ppm.	ppm.	ppm.	ppm.
0	0	21	21	25	22
0	1	45	49	61	52
0	2	49	58	48	52
20	0	22	19	20	20
20	1	42	46	47	45
20	2	49	53	56	53
40	0	24	22	26	24
40	1	51	58	52	53
40	2	43	55	56	51

Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F" value
Total	26	5,504		
Treatment	8	5,105	638	28.78**
Rates of Al	2	60	30	1.35
Rates of B	2	4,965	2,482	111.98**
Al x B	4	80	20	
Error	18	399	22	

**Significant at the .01 level

TABLE 25.-Effect of aluminum and boron applied to Elkinton fine sand on the uptake of aluminum by white clover in the second lysimeter test

Treatment		Replicates			Average
Al	B	1	2	3	
lb./acre	lb./acre	ppm.	ppm.	ppm.	ppm.
0	0	290	460	330	360
0	1	470	230	230	310
0	2	280	240	220	250
20	0	290	140	300	240
20	1	190	130	270	200
20	2	180	220	100	170
40	0	260	150	320	240
40	1	220	220	390	280
40	2	360	390	190	290

Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F" value
Total	26	246,096		
Treatment	8	82,029	10,254	1.12
Rates of Al	2	49,829	25,915	2.84
Rates of B	2	9,829	4,914	
Al x B	4	22,371	5,593	
Error	18	164,067	9,115	

TABLE 26.-Effect of aluminum and boron applied to Klichton fine sand on the uptake of calcium by white clover in the second lysimeter test

Treatment		Replicates			Average
Al	B	1	2	3	
lb./acre	lb./acre	o/o	o/o	o/o	o/o
0	0	.53	.59	.60	.57
0	1	.64	.53	.60	.62
0	2	.60	.73	.81	.71
30	0	.60	.68	.70	.68
20	1	.60	.56	.62	.59
30	0	.72	.67	.46	.62
40	0	.75	.64	.48	.62
40	1	.73	.68	.75	.72
60	0	.60	.54	.77	.60

Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F" value
Total	26	.2113		
Treatment	8	.0620	.0077	
Rates of Al	2	.0101	.0050	
Rates of B	2	.0093	.0046	
Al x B	4	.0426	.0106	1.28
Error	18	.1493	.0083	

TABLE 27.--Effect of aluminum and boron applied to Blichton fine sand on the total amounts of boron leached from lysimeters containing white clover in the second lysimeter test

Treatment		Replicates			Average
Al	B	1	2	3	
lb./acre	lb./acre	mg.	mg.	mg.	mg.
0	0	0.51	2.04	0.33	0.96
0	1	2.38	1.50	2.23	2.03
0	2	3.70	4.24	4.07	4.00
20	0	0	1.28	0.23	0.50
20	1	0.44	3.26	2.57	2.09
20	2	5.07	3.43	4.40	4.33
40	0	0.79	0.26	1.28	0.77
40	1	0.64	1.51	2.47	1.54
40	2	4.51	3.58	4.29	4.13

Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F" value
Total	26	66.9654		
Treatment	8	55.6635	6.9579	11.08**
Rates of Al	2	.1975	.0987	
Rates of B	2	54.5908	27.2954	43.47**
Al x B	4	.8752	.2188	
Error	18	11.3019	.6279	

**Significant at the .01 level

TABLE 28.—Effect of aluminum and boron in nutrient solution culture on the weights[1] of sunflower tops in the first solution culture test

Treatment		Replicates				Average
Al	B	1	2	3	4	
ppm.	ppm.	g.	g.	g.	g.	g.
0	0	0.45	0.40	0.31	0.45	0.40
0	0.5	2.75	2.70	1.67	1.55	2.17
0	1.0	2.04	2.47	1.91	2.94	2.34
0.5	0	0.28	0.43	0.38	0.32	0.33
0.5	0.5	1.69	1.86	2.13	2.13	1.95
0.5	1.0	2.74	2.94	1.79	3.74	2.80
1.0	0	0.35	0.38	0.48	0.40	0.40
1.0	0.5	0.86	2.27	2.32	2.68	2.03
1.0	1.0	2.00	2.76	1.69	3.61	2.51

[1]Oven-dry weights

Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F" value
Total	35	39.7825		
Replicates	3	2.0527	.6843	2.69
Treatment	8	31.6219	3.9527	15.53**
Rates of Al	2	.0231	.0115	
Rates of B	2	31.0782	15.5391	61.06**
Al x B	4	.5207	.1302	
Error	24	6.1079	.2545	

**Significant at the .01 level

TABLE 29.--Effect of aluminum and boron in nutrient solution culture on the weights[1] of sunflower roots in the first solution culture test

Treatment		Replicates				Average
Al	B	1	2	3	4	
ppm.	ppm.	g.	g.	g.	g.	g.
0	0	.09	.11	.09	.24	.11
0	0.5	.64	.69	.36	.34	.51
0	1.0	.45	.54	.29	.64	.48
0.5	0	.05	.13	.16	.10	.11
0.5	0.5	.37	.48	.38	.50	.42
0.5	1.0	.60	.69	.42	.81	.63
1.0	0	.10	.18	.08	.10	.12
1.0	0.5	.18	.41	.46	.59	.41
1.0	1.0	.45	.66	.32	.84	.57

[1]Oven-dry weights

Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F" value
Total	35	1.8740		
Replicates	3	.1995	.0665	4.59*
Treatment	8	1.3275	.1659	11.44**
Rates of Al	2	.0046	.0023	
Rates of B	2	1.2608	.6304	43.48**
Al x B	4	.0621	.0155	1.07
Error	24	.3470	.0145	

*Significant at the .05 level
**Significant at the .01 level

TABLE 30.—Effect of aluminum and boron in nutrient solution culture on the heights of sunflowers in the first solution culture test

Treatment		Replicates				Average
Al	B	1	2	3	4	
ppm.	ppm.	in.	in.	in.	in.	in.
0	0	5.75	3.75	3.50	4.50	4.38
0	0.5	11.00	16.75	9.25	11.50	12.12
0	1.0	13.00	12.00	11.50	13.25	12.44
0.5	0	3.25	4.00	3.00	3.25	3.37
0.5	0.5	13.25	15.00	14.75	16.50	14.87
0.5	1.0	16.50	16.00	10.50	15.75	14.70
1.0	0	3.00	2.75	6.50	2.75	3.75
1.0	0.5	9.50	20.00	13.75	19.00	15.50
1.0	1.0	10.75	16.25	13.00	16.00	14.00

Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F" value
Total	35	1,027.227		
Replicates	3	39.435	13.145	2.45
Treatment	8	858.962	107.370	20.00**
Rates of Al	2	14.880	7.440	1.46
Rates of B	2	819.816	409.908	76.36**
Al x B	4	24.465	6.116	1.14
Error	24	128.831	5.368	

**Significant at the .01 level

TABLE 31.--Effect of aluminum and boron in nutrient solution culture on the uptake of boron by sunflower tops in the first solution culture test

Treatment		Replicates				Average
Al	B	1	2	3	4	
ppm.	ppm.	ppm.	ppm.	ppm.	ppm.	ppm.
0	0	79	51	29	149	77
0	0.5	141	207	233	232	203
0	1.0	206	180	233	148	192
0.5	0	95	114	165	80	113
0.5	0.5	198	292	249	210	237
0.5	1.0	197	229	229	262	229
1.0	0	79	160	113	81	108
1.0	0.5	281	176	210	183	212
1.0	1.0	180	161	243	210	198

Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F" value
Total	35	155,217		
Replicates	3	3,464	1,155	
Treatment	8	110,782	13,848	8.11**
Rates of Al	2	7,817	3,908	2.29
Rates of B	2	101,998	50,999	29.88**
Al x B	4	967	242	
Error	24	40,971	1,707	

**Significant at the .01 level

TABLE 32.—Effect of aluminum and boron in nutrient solution culture on the uptake of boron by sunflower roots in the first solution culture test

Treatment						Average
Al	B	1	2	3	4	
ppm.	ppm.	ppm.	ppm.	ppm.	ppm.	ppm.
0	0	721	396	272	237	406
0	0.5	400	444	362	612	455
0	1.0	457	326	675	528	496
0.5	0	259	354	462	400	369
0.5	0.5	451	197	408	338	350
0.5	1.0	288	430	492	785	487
1.0	0	204	345	185	223	238
1.0	0.5	382	368	632	523	480
1.0	1.0	264	231	896	359	438

Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F" value
Total	35	1,012,174		
Replicates	3	108,168	36,056	1.28
Treatment	8	229,218	28,652	1.02
Rates of Al	2	28,661	14,330	
Rates of B	2	119,625	59,812	2.13
Al x B	4	80,932	20,233	
Error	24	674,788	28,116	

TABLE 33.—Effect of aluminum and boron in nutrient solution culture on the uptake of aluminum by sunflower tops in the first solution culture test

Treatment		Replicates				Average
Al	B	1	2	3	4	
ppm.	ppm.	ppm.	ppm.	ppm.	ppm.	ppm.
0	0	40	57	52	51	50
0	0.5	50	55	30	30	41
0	1.0	60	90	90	50	72
0.5	0	118	63	84	62	88
0.5	0.5	30	25	55	50	40
0.5	1.0	45	41	35	50	43
1.0	0	37	50	69	237	98
1.0	0.5	30	45	30	55	40
1.0	1.0	50	75	30	50	51

Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F" value
Total	35	40,182		
Replicates	3	2,241	747	
Treatment	8	14,279	1,785	1.44
Rates of Al	2	620	310	
Rates of B	2	7,656	3,828	3.10
Al x B	4	6,003	1,501	1.21
Error	24	29,662	1,236	

TABLE 34.—Effect of aluminum and boron in nutrient solution culture on the uptake of aluminum by sunflower roots in the first solution culture test

Treatment		Replicates				Average
Al	B	1	2	3	4	
ppm.	ppm.	ppm.	ppm.	ppm.	ppm.	ppm.
0	0	1160	830	1610	2170	1190
0	0.5	190	300	490	630	400
0	1.0	280	520	400	300	370
0.5	0	5790	2950	2650	900	3070
0.5	0.5	5070	2280	2120	2590	3010
0.5	1.0	6050	5390	2090	4750	4570
1.0	0	4850	4700	8020	12450	7540
1.0	0.5	6560	17600	5380	9870	9850
1.0	1.0	12390	11100	5740	3890	8280

Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F" value
Total	35	611,940,700		
Replicates	3	19,030,500	6,343,500	
Treatment	8	402,638,900	50,329,900	6.35**
Rates of Al	2	383,518,500	191,759,200	24.19**
Rates of B	2	2,025,800	1,012,900	
Al x B	4	17,094,600	4,273,600	
Error	24	190,271,300	7,928,000	

**Significant at the .01 level

TABLE 35.--Effect of aluminum and boron in nutrient solution culture on the uptake of calcium by sunflower tops in the first solution culture test

Treatment		Replicates				Average
Al	B	1	2	3	4	
ppm.	ppm.	%	%	%	%	%
0	0	0.30	0.23	0.80	0.28	0.40
0	0.5	1.33	2.16	2.25	6.84	3.14
0	1.0	2.09	2.13	2.36	6.23	3.20
0.5	0	0.84	0.24	0.39	0.34	0.45
0.5	0.5	1.02	1.10	1.69	0.89	1.17
1.0	1.0	5.39	2.73	3.56	1.27	3.24
1.0	0	0.21	0.42	0.26	0.26	0.29
1.0	0.5	1.06	1.60	2.64	1.33	1.41
1.0	1.0	7.41	4.34	3.81	6.43	6.00

Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F" value
Total	35	172.3126		
Replicates	3	7.1382	2.3794	1.13
Treatment	8	124.7476	14.3434	6.83**
Rates of Al	2	6.3985	3.1992	1.52
Rates of B	2	85.7170	42.3585	20.04**
Al x B	4	22.6321	5.6580	2.69
Error	24	50.4268	2.1011	

**Significant at the .01 level

TABLE 36.—Effect of aluminum and boron in nutrient solution culture on the uptake of calcium by sunflower roots in the first solution culture test

Treatment		Replicates				Average
Al	B	1	2	3	4	
ppm.	ppm.	%	%	%	%	%
0	0	.14	.08	.12	.06	.10
0	0.5	.04	.02	.06	.05	.04
0	1.0	.04	.05	.07	.06	.05
0.5	0	.07	.11	.10	.04	.08
0.5	0.5	.04	.04	.03	.02	.03
0.5	1.0	.04	.04	.03	.05	.04
1.0	0	.04	.06	.09	.04	.06
1.0	0.5	.04	.05	.03	.05	.04
1.0	1.0	.07	.06	.07	.03	.06

Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F" value
Total	35	.0269		
Replicates	3	.0020	.0007	1.74
Treatment	8	.0150	.0019	4.76**
Rates of Al	2	.0016	.0008	2.00
Rates of B	2	.0108	.0054	13.40**
Al x B	4	.0026	.0006	1.50
Error	24	.0099	.0004	

**Significant at the .01 level

TABLE 37.—Effect of aluminum and boron in nutrient solution culture on the weights[1] of sunflower tops in the second solution culture test

Treatment		Replicates				Average
Al	B	1	2	3	4	
ppm.	ppm.	g.	g.	g.	g.	g.
0	0	1.7	1.1	0.5	1.3	1.1
0	0.5	9.5	10.0	8.5	9.0	9.2
0	1.0	9.5	8.5	10.5	9.5	9.5
1	0	2.2	0.4	0.2	2.0	1.2
1	0.5	11.0	9.0	9.0	7.5	9.1
1	1.0	8.0	8.5	4.0	6.5	6.7
8	0	2.3	1.6	2.0	1.9	1.9
8	0.5	11.0	7.5	8.0	9.5	9.0
8	1.0	5.5	9.5	8.5	7.5	7.7

[1]Oven-dry weights

Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F" value
Total	35	334.11		
Replicates	3	3.80	1.27	
Treatment	8	395.09	49.39	33.60**
Rates of Al	2	2.29	1.14	
Rates of B	2	377.06	188.53	128.25**
Al x B	4	15.74	3.93	2.67
Error	24	35.22	1.47	

**Significant at the .01 level

TABLE 38.--Effect of aluminum and boron in nutrient solution culture on the weights[1] of sunflower roots in the second solution culture test

Treatment		Replicates				Average
Al	B	1	2	3	4	
ppm.	ppm.	g.	g.	g.	g.	g.
0	0	0.28	0.39	0.15	0.27	0.27
0	0.5	2.17	2.24	1.93	1.77	2.03
0	1.0	2.16	1.66	2.35	1.98	2.04
1	0	0.38	1.14	0.35	0.55	0.61
1	0.5	2.49	2.23	1.95	1.51	2.04
1	1.0	2.48	1.92	0.75	1.53	1.67
2	0	0.34	0.57	0.52	0.68	0.58
2	0.5	2.44	1.64	1.91	2.03	2.00
2	1.0	1.14	2.04	1.89	2.18	1.56

[1]Oven-dry weights

Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F" value
Total	35	22.5120		
Replicates	3	.5454	.1818	
Treatment	8	17.3739	2.1717	11.35**
Rates of Al	2	.0488	.0244	
Rates of B	2	16.6323	8.3161	43.45**
Al x B	4	.6922	.1732	
Error	24	4.5927	.1914	

**Significant at the .01 level

TABLE 39.--Effect of aluminum and boron in nutrient solution culture on the heights of sunflower plants in the second solution culture test

Treatment		Replicates				Average
Al	B	1	2	3	4	
ppm.	ppm.	in.	in.	in.	in.	in.
0	0	16.50	33.25	9.25	14.00	18.25
0	0.5	39.25	36.50	28.25	35.75	35.00
0	1.0	34.25	33.00	33.25	36.00	34.25
1	0	20.25	19.75	23.50	15.00	19.50
1	0.5	41.50	34.75	36.25	34.00	36.75
1	1.0	30.00	33.50	30.25	32.50	31.50
2	0	16.00	16.50	14.25	13.75	15.25
2	0.5	32.50	27.50	35.00	28.75	31.00
2	1.0	30.00	33.00	38.00	35.75	34.85

Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F" value
Total	35	2,947.07		
Replicates	3	14.86	4.95	
Treatment	8	2,691.25	336.41	57.31**
Rates of Al	2	40.75	20.37	3.47*
Rates of B	2	2,519.07	1,259.53	214.57**
Al x B	4	131.33	32.83	5.59**
Error	24	140.96	5.87	

*Significant at the .05 level
**Significant at the .01 level

TABLE 40.—Effect of aluminum and boron in nutrient solution culture on the uptake of boron by sunflower tops in the second solution culture test

Treatment		Replicates				Average
Al	B	1	2	3	4	
ppm.	ppm.	ppm.	ppm.	ppm.	ppm.	ppm.
0	0	47	73	93	79	73
0	0.5	73	90	73	82	80
0	1.0	95	89	114	103	100
1	0	28	140	73	75	79
1	0.5	80	68	83	73	76
1	1.0	92	109	91	96	97
2	0	43	84	54	60	60
2	0.5	82	101	93	88	89
2	1.0	112	96	100	87	99

Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F" value
Total	35	15,770		
Replicates	3	2,263	754	2.37
Treatment	8	5,875	734	2.31
Rates of Al	2	17	8	
Rates of B	2	4,758	2,379	7.48**
Al x B	4	1,100	275	
Error	24	7,632	318	

**Significant at the .01 level

TABLE 41.-Effect of aluminum and boron in nutrient solution culture on the uptake of boron by sunflower roots in the second solution culture test

Treatment		Replicates				Average
Al	B	1	2	3	4	
ppm.	ppm.	ppm.	ppm.	ppm.	ppm.	ppm.
0	0	340	255	230	270	275
0	0.5	165	140	165	185	164
0	1.0	180	175	175	180	177
1	0	160	290	270	180	225
1	0.5	125	140	185	175	156
1	1.0	145	185	185	165	220
2	0	215	185	395	175	242
2	0.5	160	155	195	180	172
2	1.0	175	150	195	190	177

Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F" value
Total	35	112,169		
Replicates	3	8,341	2,780	1.35
Treatment	8	54,313	6,789	3.29*
Rates of Al	2	2,788	1,394	
Rates of B	2	48,754	24,377	11.82**
Al x B	4	2,771	693	
Error	24	49,515	2,063	

*Significant at the .05 level
**Significant at the .01 level

TABLE 42.—Effect of aluminum and boron in nutrient solution culture on the uptake of aluminum by sunflower tops in the second solution culture test

Treatment		Replicates				Average
Al	B	1	2	3	4	
ppm.	ppm.	ppm.	ppm.	ppm.	ppm.	ppm.
0	0	23	40	63	48	43
0	0.5	16	24	16	24	20
0	1.0	30	16	24	26	24
1	0	36	36	32	30	33
1	0.5	20	22	16	22	20
1	1.0	28	16	20	34	24
2	0	42	43	37	30	38
2	0.5	16	30	22	24	23
2	1.0	44	28	14	20	26

Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F" value
Total	35	4,328		
Replicates	3	9	3	
Treatment	8	2,362	295	3.60**
Rates of Al	2	71	35	
Rates of B	2	2,087	1,043	12.80**
Al x B	4	204	51	
Error	24	1,957	82	

**Significant at the .01 level

TABLE 13.--Effect of aluminum and boron in nutrient solution culture on the uptake of aluminum by sunflower roots in the second solution culture test

Treatment		Replicates				Average
Al	B	1	2	3	4	
ppm.	ppm.	ppm.	ppm.	ppm.	ppm.	ppm.
0	0	660	360	440	800	570
0	0.5	180	290	180	140	200
0	1.0	120	200	240	150	180
1	0	2330	680	2130	2400	1880
1	0.5	1150	1500	1170	1000	1200
1	1.0	1500	1100	3000	1100	1700
2	0	7910	3340	6570	7000	6200
2	0.5	1570	2550	2050	2220	2100
2	1.0	3150	2900	2550	2950	2900

Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F" value
Total	35	128,083,100		
Replicates	3	2,379,200	793,100	1.29
Treatment	8	110,896,500	13,862,100	22.47**
Rates of Al	2	71,543,900	35,771,900	57.98**
Rates of B	2	19,306,100	9,653,000	15.64**
Al x B	4	20,046,500	5,011,600	8.12**
Error	24	14,807,400	617,000	

**Significant at the .01 level

TABLE 44.—Effect of aluminum and boron in nutrient solution culture on the uptake of calcium by sunflower tops in the second solution culture test

Treatment		Replicate				Average
Al	B	1	2	3	4	
ppm.	ppm.	%	%	%	%	%
0	0	1.07	0.88	0.60	0.78	0.83
0	0.5	1.36	1.34	0.69	1.42	1.20
0	1.0	0.93	1.35	1.28	0.93	1.14
1	0	1.57	1.87	1.74	1.71	1.72
1	0.5	1.20	1.07	1.29	1.16	1.18
1	1.0	2.47	1.79	1.29	1.32	1.71
2	0	0.94	1.16	1.33	1.30	1.18
2	0.5	1.28	1.65	1.56	1.56	1.51
2	1.0	1.02	1.38	1.39	1.99	1.44

Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F" value
Total	35	5.0227		
Replicates	3	.1097	.0366	
Treatment	8	2.7752	.3469	3.89**
Rates of Al	2	1.4491	.7245	8.11**
Rates of B	2	.2232	.1116	1.25
Al x B	4	1.1066	.2766	3.10*
Error	24	2.1378	.0891	

*Significant at the .05 level
**Significant at the .01 level

TABLE 45.—Effect of aluminum and boron in nutrient solution culture on the uptake of calcium by sunflower roots in the second solution culture test

Treatment		Replicates				Average
Al	B	1	2	3	4	
ppm.	ppm.	%	%	%	%	%
0	0	.06	.05	.09	.06	.07
0	0.5	.14	.13	.17	.14	.15
0	1.0	.15	.11	.10	.13	.12
1	0	.07	.14	.05	.06	.08
1	0.5	.14	.05	.06	.05	.07
1	1.0	.12	.10	.07	.07	.09
2	0	.10	.05	.06	.11	.08
2	0.5	.10	.10	.12	.07	.10
2	1.0	.09	.10	.08	.08	.09

Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F" value
Total	35	.0407		
Replicates	3	.0032	.0011	1.57
Treatment	8	.0215	.0027	3.85**
Rates of Al	2	.0063	.0031	4.44*
Rates of B	2	.0069	.0034	4.86*
Al x B	4	.0084	.0021	3.00*
Error	24	.0160	.0007	

*Significant at the .05 level
**Significant at the .01 level

TABLE 46.--Effect of aluminum in nutrient solution culture on the weights[1] of sunflower tops in the third solution culture test

Treatment	Replicates				Average
Al	1	2	3	4	
ppm.	g.	g.	g.	g.	g.
0	12.5	14.5	10.0	18.5	13.9
2	11.0	11.0	11.5	16.5	12.5
4	14.0	17.5	13.5	14.0	14.7
6	7.5	5.0	10.0	7.5	7.5
8	6.0	8.0	3.5	6.0	5.9
10	6.5	5.0	4.5	6.5	5.6
12	3.0	3.5	4.0	3.5	3.4
14	4.0	4.5	2.0	4.0	3.7
16	2.0	2.0	2.5	3.0	2.4

[1]Oven-dry weights

Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F" value
Total	35	825.74		
Rates of Al	8	724.55	90.57	26.56**
Replicates	3	19.46	6.49	1.90
Error	24	81.73	3.41	

**Significant at the .01 level

TABLE 47.—Effect of aluminum in nutrient solution culture on the weights[1] of sunflower roots in the third solution culture test

Treatment	Replicates				Average
Al	1	2	3	4	
ppm.	g.	g.	g.	g.	g.
0	3.80	4.05	3.45	5.45	4.20
2	4.35	4.25	4.60	5.55	4.60
4	4.55	4.90	5.00	4.60	4.75
6	2.40	2.35	3.55	3.15	2.80
8	2.00	2.60	1.60	1.70	1.95
10	2.20	1.70	1.85	2.20	2.00
12	1.80	1.35	1.10	1.30	1.35
14	1.10	0.90	1.85	1.20	1.30
16	0.90	0.90	0.60	1.00	0.85

[1]Oven-dry weights

Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F" value
Total	35	80.3769		
Rates of Al	8	73.6712	9.2089	34.36**
Replicates	3	.2736	.0912	
Error	24	6.4321	.2680	

**Significant at the .01 level

TABLE 48.--Effect of aluminum in nutrient solution culture on the heights of sunflower plants in the third solution culture test

Treatment	Replicates				Average
Al	1	2	3	4	
ppm.	in.	in.	in.	in.	in.
0	13.50	23.00	25.00	30.00	25.35
2	23.75	21.50	20.75	24.00	22.50
4	28.75	27.50	22.60	21.50	24.95
6	20.75	17.00	21.75	20.50	20.00
8	19.75	17.00	15.25	19.50	17.90
10	21.75	13.50	17.25	18.00	13.10
12	13.50	18.25	14.75	15.50	15.50
14	18.75	14.50	11.75	15.00	15.00
16	15.25	18.00	10.00	13.75	13.75

Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F" value
Total	35	757.77		
Rates of Al	8	580.78	72.60	13.06**
Replicates	3	43.60	14.53	2.61
Error	24	133.39	5.59	

**Significant at the .01 level

TABLE 49. Effect of aluminum in nutrient solution culture on the uptake of boron by sunflower tops in the third solution culture test

Treatment	Replicates				Average
Al	1	2	3	4	
ppm.	ppm.	ppm.	ppm.	ppm.	ppm.
0	100	109	109	105	103
2	112	117	127	125	120
4	109	106	117	113	111
6	101	111	109	109	107
8	95	97	109	97	99
10	92	97	118	115	105
12	108	97	95	117	104
14	101	108	121	101	108
16	116	97	111	93	108

Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F" value
Total	35	2,985		
Rates of Al	8	1,081	153	2.29
Replicates	3	478	159	2.69
Error	24	1,428	59	

TABLE 50.-Effect of aluminum in nutrient solution culture on the uptake of boron by sunflower seeds in the third solution culture test

Treatment	Replicates				Average
Al	1	2	3	4	
ppm.	ppm.	ppm.	ppm.	ppm.	ppm.
0	185	205	95	100	130
2	160	150	115	90	125
4	150	115	95	90	110
6	145	220	95	90	135
8	190	175	115	170	160
10	175	190	205	105	145
12	90	185	120	120	130
14	175	115	90	130	130
16	135	175	85	110	125

Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F" value
Total	35	30,919		
Rates of Al	8	6,600	825	
Replicates	3	24,302	9,634	9.54**
Error	24	20,217	842	

TABLE 31.-Effect of aluminum in nutrient solution culture on the uptake of aluminum by sunflower tops in the third solution culture test

Treatment	Replicates				Average
Al	1	2	3	4	
ppm.	ppm.	ppm.	ppm.	ppm.	ppm.
0	26	26	16	24	26
2	24	26	32	18	26
4	48	22	16	19	26
6	18	34	23	21	26
8	19	26	16	40	29
10	26	32	22	38	28
12	31	22	32	18	26
14	26	26	50	26	48
18	24	26	37	24	26

Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F" value
Total	35	6,261		
Rates of Al	8	1,936	242	1.61
Replicates	3	729	243	1.62
Error	24	3,596	150	

TABLE 52.--Effect of aluminum in nutrient solution culture on the uptake of aluminum by sunflower roots in the third solution culture test

Treatment					Average
Al	1	2	3	4	
ppm.	ppm.	ppm.	ppm.	ppm.	ppm.
0	160	120	120	120	130
2	1100	800	1200	500	900
4	1600	1200	1000	1300	1200
6	3800	4200	3000	3000	3300
8	6200	3300	5600	4200	4800
10	5900	6200	4200	6800	5700
12	11600	5000	5000	8600	7500
14	5600	9600	4600	7600	6800
16	8600	9000	10600	8400	9100

Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F" value
Total	35	384,763,200		
Rates of Al	8	327,620,500	4,095,262	18.57**
Replicates	3	4,226,600	140,900	
Error	24	5,291,610	220,480	

**Significant at the .01 level

TABLE 53.-Effect of aluminum in nutrient solution culture on the uptake of calcium by sunflower tops in the third solution culture test

Treatment Al	Replicates 1	2	3	4	Average
ppm.	o/o	o/o	o/o	o/o	o/o
0	.80	.72	.64	.80	.74
2	.80	.64	.72	.64	.70
4	.80	.72	.77	.64	.73
6	.77	.72	.84	.64	.74
8	.80	.75	.59	.84	.69
10	.80	.59	.80	.69	.72
12	.80	.77	.80	.64	.75
14	.77	.64	.72	.64	.69
16	.80	.59	.72	.64	.69

Analysis of variance

Source of variation	Degrees of freedom	Sum of square	Mean square	"F" value
Total	35	.2054		
Rates of Al	8	.0196	.0024	
Replicates	3	.0927	.0309	7.92**
Error	24	.0931	.0039	

**Significant at the .01 level

TABLE 54.--Effect of aluminum in nutrient solution culture on the uptake of calcium by sunflower roots in the third solution culture test

Treatment	Replicates				Average
Al	1	2	3	4	
ppm.	%	%	%	%	%
0	.91	.40	.79	.88	.74
2	.44	.75	.75	.60	.63
4	.55	.34	.46	.35	.35
6	.46	.46	.36	.35	.35
8	.46	.50	.40	.60	.60
10	.46	.46	.28	.55	.55
12	.35	.36	.32	.34	.34
14	.39	.35	.32	.32	.30
16	.36	.24	.29	.28	.28

Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean square	"F" value
Total	35	1.0393		
Rates of Al	8	.6937	.0867	6.37**
Replicates	3	.0194	.0065	
Error	24	.3262	.0136	

**Significant at the .01 level

BIOGRAPHY

Charles Carpenter Hortenstine was born January 30, 1919, in Galax, Virginia, the son of James Wilson Hortenstine and Martha Robinson Hortenstine. He attended William King High School in Abingdon, Virginia, graduating in June, 1936. He attended Virginia Polytechnic Institute for one year and Emory and Henry College for one year after graduating from high school.

On September 9, 1939, he enlisted in the U. S. Army Air Corps. He served in the continental United States, Canada, Labrador, and the South Pacific Theater. He was separated from the service on March 3, 1946, and presently holds the rank of Major in the U. S. Air Force Reserves.

In March, 1946, he entered the Alabama Polytechnic Institute, Auburn, Alabama, where he received the degree of Bachelor of Science in Agriculture in March, 1948. He was employed by the Bureau of Entomology and Plant Quarantine, United States Department of Agriculture, in Mobile, Alabama, from March, 1948, until June, 1954. From June, 1954, until December, 1954, he was engaged in commercial pest control work. In January, 1955, he re-entered Alabama Polytechnic Institute where he received the degree of Master of Science in Agronomy in August, 1957. He entered the University of Florida in September, 1957. He is now a candidate for the degree of Doctor of Philosophy.

He is an associate member of the Society of Sigma Xi and a member of Gamma Sigma Delta and Alpha Zeta agricultural honorary fraternities. He is a member of the American Society of Agronomy.

This dissertation was prepared under the direction of the chairman of the candidate's supervisory committee and has been approved by all members of that committee. It was submitted to the Dean of the College of Agriculture and to the Graduate Council and was approved as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

August 8, 1969

M. A. Brooker

Dean, College of Agriculture

Dean, Graduate School

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